LBL-22372
UC-95d

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY

DEC 23 1986

LIBRARY AND
DOCUMENTS SECTION

APPLIED SCIENCE DIVISION

DESIGN OPTIONS FOR ENERGY EFFICIENCY IMPROVEMENT OF RESIDENTIAL APPLIANCES

I. Turiel

October 1986

TWO-WEEK LOAN COPY

This is a Library Circulating Copy
which may be borrowed for two weeks.

APPLIED SCIENCE
DIVISION

LBL-22372 c.2

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

LBL -22372

DESIGN OPTIONS FOR ENERGY EFFICIENCY IMPROVEMENT OF RESIDENTIAL APPLIANCES

Isaac Turiel*

Energy Analysis Program
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
October 1986

This work was supported by the U. S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Equipment Division, under contract DE-AC03-76SF00098.

*Portions of Arthur D. Little reports on six of thirteen appliances were incorporated into this document.

TABLE OF CONTENTS

	PAGE
Executive Summary	i
Introduction	1
Refrigerators and Freezers	4
Dishwashers	15
Clothes Dryers	20
Water Heaters	25
Room Air Conditioners	36
Home Heating Equipment	40
Televisions	44
Ranges and Ovens	47
Clothes Washers	51
Humidifiers and Dehumifiers	56
Central Air Conditioners, including Heat Pumps	59
Furnaces and Boilers	67
Acknowledgments	72

EXECUTIVE SUMMARY

This report presents information needed for the Department of Energy (DOE) appliance standards evaluation effort. The appliances discussed are refrigerator/freezers, freezers, dishwashers, clothes dryers, water heaters, room air conditioners, home heating equipment, television sets, kitchen ranges and ovens, clothes washers, humidifiers and dehumidifiers, central air conditioners (including heat pumps), and furnaces. In the original standards analysis, completed in the early 1980's, DOE segregated the basic models of each product type into separate classes to which different energy efficiency standards would apply. As mandated by the National Energy Conservation Act, the classes were differentiated by type of energy used, and capacity or performance-related features which provided utility to the consumer and affected efficiency.

The purpose of this report is to identify the changes that have taken place in the products since the early 1980's, suggest possible revisions to product classes, and update the selection of design options for energy efficiency improvement. Product classes are recommended for each of these 13 product types. Design options to improve energy efficiency are described for each of the product types. Options used in foreign products and in the prototype stage of development are included. The following 13 tables contain a list and brief description of each suggested design option. Future publications will discuss the change in efficiency brought about by each design change and the cost of products of improved efficiency.

Lawrence Berkeley Laboratory (LBL) carried out the research and wrote the reports for dishwashers, water heaters, home heating equipment, televisions, clothes washers, humidifiers and dehumidifiers. Much of the section on central air conditioners (including heat pumps) was derived from a report, "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", by Dennis L. O'Neal, Curtis L. Boecker, William E. Murphy, and James R. Notman. Survey reports for the six remaining products were written by Arthur D. Little under contract to LBL. Portions of the Arthur D. Little documents are incorporated into this report. While we acknowledge support received from the above sources, any errors or omissions are the responsibility of the author.

TABLE 1. DESIGN OPTIONS FOR REFRIGERATOR-FREEZER

1) *Foam Insulation Substitution in Doors*
Fiberglass insulation is replaced with polyurethane foam insulation. Since polyurethane foam has a thermal conductivity lower than that of fiberglass, this option reduces total cabinet heat leakage.

2) *Increased door Insulation Thickness*
Foam door insulation is increased to a nominal thickness of 2 inches to further reduce heat leakage.

3) *High-Efficiency Compressor Substitution*
A high-efficiency compressor replaces a conventional design.

4) *Double Door Gasket*
An additional inner door seal gasket reduces heat leakage and air infiltration through the door.

5) *Anti-Sweat Heater Switch*
Cabinet heaters prevent condensation on the cabinet exterior in high humidity. A switch is installed, which can be used in a dry environment to shut off the heaters. Energy savings are realized by eliminating both the heater power consumption and the heat that flows into the cold space from these heaters, which must be removed by the refrigeration system. In baseline units with a hot gas loop, this option includes replacing this loop with electric resistance wire.

6) *Increased Cabinet Insulation Thickness*
Foam cabinet insulation is increased to a nominal 2 inches to decrease heat leakage.

7) *Reduce Heat Load of Through-the-Door Feature*
Improved insulation can be used to decrease the heat leakage and additional power consumption attributable to the through-the-door service feature (ice, water etc.).

8) *Increased Evaporator Surface Area*
Increased heat exchanger surface area in the evaporator produces more efficient operation of the refrigeration system.

9) *Hybrid Evaporator*
The use of separate evaporators in the refrigerator and freezer compartments of a refrigerator-freezer increases performance by reducing defrost requirements, fan power consumption and door gasket air leakage.

10) *Adaptive Defrost Control*
The use of "smart" controls to adjust the interval between defrost cycles has the potential for saving significant energy depending on the refrigerator model, usage, and ambient conditions in which the product is located.

11) *Fan And Fan Motor Improvement*
Using new technologies (e.g., dry-film capacitor motors) improved fans can replace the conventional types.

12) *Enhanced Heat Transfer Surfaces*
Improvements in the rate of heat transfer would be obtained by modifying the heat transfer surfaces.

13) *Mixed Refrigerants*
Mixed refrigerants may improve performance through enhanced capacity modulation. Thus far, this option has not provided any practical improvements in performance in refrigerator-freezers.

14) *Fluid Control Valves*
To control refrigerant flow , at specially high load conditions, an automatic, adjustable expansion valve instead of the traditional capillary tube can provide better performance.

15) *Improved Foam Insulation*
Improvements in the cell structure and the solid conduction of the foam should result in some overall product energy efficiency.

16) *Evacuated Insulation Panels*
Using evacuated panels in the large planar walls of the cabinet reduces heat transfer through the panels.

17) *Two Compressor System*
Refrigerator/freezers can operate more efficiently with separate refrigeration systems for the refrigerator and freezer compartments.

18) *Use Of Natural Convection Currents*
The use of natural convection currents (such as in some two compressor refrigerator/ freezers) in lieu of fans eliminates electricity use for the fans and reduces the load on the refrigeration system.

19) *Location Of Compressor And Condensers*
Top mounted compressors and condensors can cool more efficiently, since they can run cooler, due to heat being more readily convected away from the refrigeration system.

TABLE 2. DESIGN OPTIONS FOR FREEZERS

1) *Foam Insulation Substitution In Cabinet*
The 2-1/2 inch thick fiberglass cabinet insulation is replaced with 2-1/2 inches of polyurethane foam. The lower conductivity of foam reduces cabinet heat leakage.

2) *Foam Insulation Substitution In Door*
Fiberglass insulation in the freezer door is replaced with polyurethane foam insulation. Since polyurethane foam has a thermal conductivity lower than that of fiberglass, this option reduces total cabinet heat leakage.

3) *Increased Cabinet Insulation Thickness*
Foam cabinet insulation is increased to a nominal 2-1/2 inches to further decease heat leakage (chest freezer only)

4) *Increase Door Insulation Thickness*
Foam door insulation is increased to a nominal thickness of 2 inches to further reduce heat leakage (chest freezer only)

5) *High-Efficiency Compressor Substitution*
A high-efficiency compressor replaces a conventional design.

6) Double Door Gasket
An additional inner door seal gasket reduces heat leakage and air infiltration in the door area.

7) *Adaptive Defrost Control*
The use of "smart" controls to adjust the interval between defrost cycles has the potential for saving significant energy depending on the refrigerator model, usage, and ambient conditions in which the product is located.

8) *Fan And Fan Motor Improvement*
Using new technologies (e.g., dry-film capacitor motors) improved fans can replace the conventional types.

9) *Enhanced Heat Transfer Surfaces*
Improvements in the rate of heat transfer would be obtained by modifying the heat transfer surfaces.

10) *Mixed Refrigerants*
Mixed refrigerants may improve performance through enhanced capacity modulation. Thus far, this option has not provided any practical improvements in performance in refrigerator-freezers.

11) *Fluid Control Valves*
To control refrigerant flow , at specially high load conditions, an automatic, adjustable expansion valve instead of the traditional capillary tube can provide better performance.

12) *Improved Foam Insulation*
Improvements in the cell structure and the solid conduction of the foam should result in some overall product energy efficiency.

13) *Evacuated Insulation Panels*
Using evacuated panels in the large planar walls of the cabinet reduces heat transfer through the panels.

14) *Use Of Natural Convection Currents*

The use of natural convection currents (such as in some two compressor refrigerator/ freezers) in lieu of fans eliminates electricity use for the fans and reduces the load on the refrigeration system.

15) *Location Of Compressor And Condensers*

Top mounted compressors and condensors can cool more efficiently, since they can run cooler, due to heat being more readily convected away from the refrigeration system.

TABLE 3. DESIGN OPTIONS FOR DISHWASHERS

1) *Improved Food Filters*
Improving the design of filters to remove sufficient food particles to reduce rinse and wash cycles would allow for a reduction in hot water use.

2) *Improved Spray Arm Geometry*
Improving the spray arms to more efficiently remove food particles could allow for a reduction in hot water use and improve the dishwasher's efficiency.

3) *Improved Fill Control*
The fill control must be modified to admit a lower volume of water.

4) *Modified Sump Geometry*
The amount of water used for each cycle can be reduced by a change in the geometry of the sump.

5) *Optional Power Dry*
The elimination of electrical heating and use of the air dry option will save electrical energy and improve the overall efficiency.

6) *Reduced Inlet Water Temperature*
A reduction in the inlet water temperature from 140 ^{o}F to 120 ^{o}F would save about 18% of total energy used by a dishwasher.

7) *Improved Motor Efficiency*
An electric motor efficiency improvement from about 45% to 60% would result in 3% decrease in dishwasher energy use

8) *Increase Insulation*
Additional insulation around the tub will decrease heat losses further which in turn would allow the use of a lower water temperature as well as increasing the drying efficiency.

TABLE 4. DESIGN OPTIONS FOR CLOTHES DRYERS

1) *Automatic Termination By Moisture Sensing*
This design option reduces the energy used by ensuring that a dryer is turned off as soon as the moisture is removed from the clothes.

2) *Automatic Termination By Temperature Sensing*
This design option reduces energy consumption by terminating the drying cycle when the temperature of the exiting air rises by a preset amount.

3) *Insulation*
During the dry cycle, some areas of the lower cabinet are at temperatures above room temperature. This results in standby losses, which can be reduced by the use of insulation.

4) *Use Of Condenser*
In electric dryers, a heat exchanger is used to condense moisture out of the exiting air stream from the dryer. The air is then recirculated saving some of the energy needed to heat the air from ambient to drying temperature.

5) *Use Of Recycle Heat Exchanger*
Reintroducing a portion of the exhaust air stream at the dryer air inlet, some of the energy in the exhaust stream is recovered and efficiency is increased.

6) *Inlet Air Preheat*
A heat exchanger is used in this option to recover exhaust energy to preheat inlet air.

7) *Modified Operating Conditions*
Improving the operating conditions to an optimum would result in an increased efficiency.

8) *Use Of Heat Pumps*
An electric heat pump can be used to remove heat from the exhaust stream and return it to the dryer at high temperatures.

9) *Use Of Microwave Dryer*
Damp clothes can be dried by absorption of electromagnetic energy and conversion to heat energy.

TABLE 5. DESIGN OPTIONS FOR WATER HEATERS

1) *Jacket Insulation*
Increased use of of insulation reduces standby losses and increases efficiency.

2) *Heat Traps*
Thermal traps can be used to break the convective loop which is a source of heat loss from the storage tank to the feed lines above.

3) *Reduction Of Heat Leaks From Fittings*
Heat leaks through fittings can be reduced by combining or isolating fittings from the outer tank cover.

4) *Reduced Pilot Light Input Rate*
A reduction in pilot light heat rate reduces standby losses for gas fired water heaters. A reduced pilot light input can be obtained by replacing the pilot jet with one of a smaller orifice size.

5) *Automatic Ignition With A Flue Damper*
Elimination of a continuous pilot light, substitution of an electric ignition and the use of a flue damper is an effective combination of measures to reduce standby losses in a gas-fired water heaters.

6) *Elimination Of Central Flue And Indirect Heating Of Water*
Indirect heating will reduce much of the standby loss caused by convection of heat energy up a central flue.

7) *Increased Flue Baffling With Forced Draft*
The recovery efficiency of gas or oil-fired water heaters can be increased by restricting the total air flow with increased baffling of combustion gases as they pass through the central flue. Increased baffling can be achieved by adding interference tabs or by manufacturing the flue baffles as a series of reversing spirals.

8) *Multiple Flues*
Increased heat transfer with multiple flues, which have more surface area to transfer heat energy to the surrounding water, increases the recovery efficiency of gas-fired or oil-fired water heaters.

9) *Submerged Combustion Chamber*
Using a submerged combustion chamber increases the recovery efficiency and reduces standby losses.

10) *Use Of Pulsed Combustion*
Pulsed combustion provides a more efficient transfer of heat energy to the water. Recovery efficiency can improve substantially for gas-fired and oil-fired water heaters.

11) *Condensation Of Flue Gases*
Some input fuel energy could be recaptured by condensation of all the water vapor in the combustion products, and so its heat of vaporization will be available to further increase the water temperature and improve recovery efficiency for gas and oiled-fired water heaters.

12) *Heat Pump Water Heaters*

Design options for improving the energy efficiency of heat pump water heaters can be separated into two catagories; those common to gas-fired, oil-fired, and electric resistance storage type water heaters (described earlier) and options that improve the efficiency of heat pumps. The former include increased jacket insulation (for heat pump water heaters with a tank), use of anti convection valves, and reduction of heat "leaks". The latter includes

- For heat pump water heaters with a tank; Increased heat exchanger effectiveness, Improved compressor efficiency, Improved fan and fan motor efficiencies, Improved compressor motor efficiency
- For heat pump water heaters without a tank; Increased heat exchanger effectiveness for evaporator and condenser, Improved compressor efficiency, Improved fan and fanmotor efficiency, Improved compressor motor efficiency, Improved water circulating pump and pump motor efficiencies, Improved heat exchanger insulation, Improved connection hose insulation.

13) *Instantaneous Water Heaters*

A design option that would reduce energy use for both gas and electric instantaneous water heaters would be one that minimizes the amount of leftover water in the heater after each draw Gas-fired instantaneous water heaters can be designed to be more efficient by employing a reduced pilot light input rate, by use of automatic ignition with a flue damper, increased flue baffling with forced draft, and use of multiple flues. Advanced design options such as pulsed combustion and condensation are also potential conservation measures for gas-fired instantaneous water heaters.

TABLE 6. DESIGN OPTIONS FOR ROOM AIR CONDITIONERS

1) *Increase Heat Transfer Surface Area*
An increase in the heat exchanger depth increases the efficiency slightly. As the heat transfer is increased, the compressor displacement must be reduced to maintain the desired unit capacity.

2) *Improve Fan and Fan Motor Efficiency*
Centrifugal forward curved fans can be used to improve mechanical efficiency and split capacitor type motors can be substituted for shaded pole motors to improve motor efficiency.

3) *Improved Compressor Efficiency*
With the introduction of rotary and scroll compressors, up to 20% improvement in compressor efficiency would be obtained. The benefits of these are generally lower valve and mechanical friction losses.

4) *Variable Speed Compressors*
The variable speed motor control combined with the rotary or scroll compressor can provide equivalent cooling capacities with much smaller hardware and also operate at lower, more efficient speeds when the cooling requirement is reduced.

5) *Mixed Refrigerants*
Mixed refrigerants (non-azeotropic) can improve efficiency by providing more ideal heat exchanger characteristics. It is estimated that as much as a 10% improvement in efficiency could be achieved with mixed refrigerants.

6) *Electronic Expansion Valves*
Electronic expansion valves will allow for better control of refrigerant flow conditions. A microprocessor sends a signal to the valve, controlling its opening and closing.

7) *Thermostatic Cyclic Controls*
These remote temperature controls more accurately monitor room air temperature than the current build-in thermostats.

TABLE 7. DESIGN OPTIONS FOR HOME HEATING EQUIPMENT (NOT INCLUDING FURNACES)

1) *Increase Heat Exchanger Surface Area*
Increase in heat transfer rate by increasing the heat exchanger's surface area will improve the steady-state efficiency of home heating equipment.

2) *Intermittent Ignition Device*
Intermittent ignition devices can be used in gas-fired home heating equipment instead of pilot lights. This device, which requires electrical power, eliminates pilot losses.

3) *Vent Damper (Electrical and Thermal)*
Off- cycle convective heat losses can be significantly reduced with the use of a vent damper.

4) *Improve Blower Motor Efficiency*
A small overall efficiency improvement can be accomplished by using more efficient fans and fan motors.

5) *Power Burner or Power Vent*
The advantages of providing power venting include a greater degree of control of combustion air thus limiting excess air, and restriction of air flow through the flue during off-cycle conditions, thus reducing off-cycle heat exchanger losses.

6) *Pulsed Combustion and Condensation Heaters*
Condensation of water vapor can be used to improve steady state efficiency of home heating equipment.

7) *Modulating Burners*
Modulating fuel and air inputs increases the on-time of a heating system, and so the seasonal efficiency of home heating equipment could be improved.

TABLE 8. DESIGN OPTIONS FOR TELEVISIONS

1) *Remote Control*
   Eliminate or reduce energy use of remote control device.

2) *Electronic Tuning*
   Reduce energy use of electronic tuning system.

3) *Automatic Color Control*
   Reduce energy use of automatic color control system.

4) *Vertical Interval Reference*
   Reduce energy use of vertical interval reference system.

5) *Brightness Sensor*
   Improve efficiency of brightness sensor.

6) *Voltage Regulating Power Source*
   Provide requlation with a smaller internal power dissipation.

7) *Display Device*
   Replacement of the Cathode ray picture tube by a less energy intensive display device.

8) *One-Gun Tube*
   Replacement of the color television's three electron guns by one gun.

TABLE 9. DESIGN OPTIONS FOR HOUSEHOLD RANGES AND OVENS

1) *Improved Insulation*
Denser fiberglass insulation is used to reduce losses. Increased insulation thickness was not considered a viable option as it requires a reduction in cavity size and a corresponding reduction in consumer utility.

2) *Reduced Vent Size*
Vent rate in standard ovens is reduced to the rate of self-cleaning ovens by either reducing the vent tube size or adding a baffle.

3) *Reduced Conduction Losses*
Standard oven suspension has been upgraded to the level of self-cleaning ovens. This includes modifications at the door including an additional thermal break, an improved gasket and a modified inner panel.

4) *Improved Contact Conductance*
This applies to sheath-type electrical resistance cooking tops. Their efficiency is improved by designing them to maintain better thermal contact with cooking utensils.

5) *Insulation With Lower Conductivities*
Evacuated panel insulation may be used if high temperature use can be accomplished.

6) *Use of Reflective Surfaces*
The use of surfaces that reflect infra-red radiation will allow more heat energy to be retained within the oven cavity.

7) *Reduction of Thermal Mass*
A reduction of thermal mass in the stove top and oven will reduce heating energy use.

TABLE 10. DESIGN OPTIONS FOR CLOTHES WASHERS

1) *Eliminate Warm Rinse*
Elimination of the warm rinse option will reduce hot water consumption.

2) *Improve Fill Control*
Using an automatic device that could adjust the water level according to the amount and type of clothes and on the kind of dirt on the clothes, would allow hot water use to be minimized.

3) *Change Configuration To Reduce Water Use*
Any change in geometry that could reduce water usage will reduce hot water energy consumption and increase the overall efficiency.

4) *Reduce Thermal Mass*
Reducing the mass of the tub and choosing a material of lower specific heat will reduce the transfer of heat energy from the hot water to the tub.

5) *Save suds*
There will be a reduction in energy, detergent and water use if more than one load of wash is done per day and the suds saving feature is utilized.

6) *Add Insulation*
Adding insulation will improve the efficiency slightly by allowing a small decrease in the inlet water temperature.

7) *Improve Motor Efficiency*
Improving the electric motor by replacing the split phase motor by a capacitator type motor will improve the power factor and so increase the total efficiency.

8) *Add Thermostatically Controlled Mixing Valves*
The use of a thermostatically controlled mixing valve would assure a more uniform water washing temperature and would minimize the use of hot water.

9) *Electrolytic Dissociation of Water*
By substituting the electrolytic production of bleaching agents for the warming process a reduction in hot water usage would be obtained.

10) *Ultrasonic Vibration*
Mechanical energy can be delivered through ultrasonic vibrations that loosen and remove some of the dirt on the soiled clothes. This option reduces the need for hot water.

TABLE 11. DESIGN OPTIONS FOR HUMIDIFIERS AND DEHUMIDIFIERS

• HUMIDIFIERS

1) *Add A Humidistat*
By adding a humidistat excessive humidity levels are avoided and energy consumption is minimized.

2) *Improve Fan Motor Efficiency*
By improving fan motor efficiency, such as by replacing the shaded pole motion by capacitor type motors, additional improvement in the overall efficiency will be obtained.

• DEHUMIDIFIERS

1) *Improve Compressor Efficiency*
With the introduction of rotary and scroll compressors, up to 20% improvement in compressor efficiency would be obtained. The benefits of these are generally lower valve and mechanical friction losses.

2) *Improve Condenser Heat Transfer*
An increase in the heat exchanger depth increases the efficiency slightly. As the heat transfer is increased, the compressor displacement must be reduced to maintain the desired unit capacity.

3) *Improve Fan and Fan Motor Efficiency*
Centrifugal forward curved fans can be used to improve mechanical efficiency and split capacitor type motors can be substituted for shaded pole motors to improve motor efficiency.

4) *Variable Speed Compressor Motors*
This option allows better matching of heating and cooling loads to heat pump capacity and, therefore, improves part-load efficiency.

5) *High Performance Heat Transfer Surfaces*
This option includes perforated plate fins and high-density spine fins as well as internal fins in refrigerant tubes that can transfer more energy per unit area than the current surfaces.

6) *Mixed/New Refrigerants*
Nonazeotropic refrigerants mixtures by offer reduced compressor power for the same refrigeration capacity (compared to standard refrigerant) and capacity modulation.

7) *Variable Speed Fan Motors*
To improve capacity control multi-speed or variable-speed fan motors can be used.

8) *Electronic Expansion Valve*
Efficiency improvement is expected by using electronic expansion valves, which make it possible to obtain better control of flow conditions.

TABLE 12. DESIGN OPTIONS FOR CENTRAL AIR CONDITIONERS INCLUDING HEAT PUMPS

1) *Increase Heat Exchanger Surface Area*
Improvements in heat transfer rates of condenser and evaporators will be obtained if the heat transfer surface area is increased by adding more frontal area, adding tube rows, and increasing the fin density.

2) *Decrease Compressor Size*
In conjunction with option 1, in order to maintain rated capacity, compressor size must be reduced when heat exchanger performance is increased. A smaller compressor consumes less power than a large one.

3) *Improve Fan and Fan Motor Efficiency*
Improving fan and fan motor efficiency by using centrifugal forward curved fans and split capacitor type motors instead of traditional types.

4) *Use of a Two-Speed Compressor*
The two-speed compressor can operate at low speed when the building heating or cooling load is high, resulting in a substantially reduced power requirement.

5) *Variable-Speed Compressor Motors*
This option allows better matching of heating and cooling loads to heat pump capacity and, therefore, improves part-load efficiency.

6) *Two-and Variable-Speed Fan Motors*
To improve capacity control muti-speed or variable-speed fan motors can be used.

7) *New/Mixed Refrigerants*
Nonazeotropic refrigerants mixtures offer reduced compressor power for the same refrigeration capacity (compared to standard refrigerant) and capacity modulation.

8) *Use Demand Defrost Control System*
Improvement in the heating seasonal performance factor is observed with a demand defrost control relative to a time control system.

9) *Increase Compressor Efficiency*
The efficiency of the compressor can be increased by either using a more efficient motor to drive the device or by increasing the intrinsic efficiency of the compressor itself. Improvements in scroll compressor design have been reported.

10) *High-Performance Heat Transfer Surface*
This option includes perforated plate fins and high-density spine fins as well as internal fins in refrigerant tubes that can transfer more energy per unit area than the current surfaces.

11) *Electronic Expansion Valves*
Efficiency improvements is expected by using electronic expansion valves, which make it possible to obtain better control of flow conditions.

TABLE 13. DESIGN OPTIONS FOR FURNACES AND BOILERS

1) *Increased Heat Exchanger Surface Area*
This design option involves increasing the size of the heat exchanger to improve heat recovery. It can be utilized in both gas-fired and oil-fired furnaces and boilers.

2) *Intermittent Ignition Device(IID)*
Intermittent ignition devices are used in gas fired furnaces in place of pilots. The IID's require electrical hook-up.

3) *Stack Damper*
Stack dampers are used to reduce losses during the standby period. The stack damper is electrically powered and wired into the control system so that it opens prior to the firing of the furnace or boiler and closes after the firing period is terminated.

4) *Power Burner Or Power Vent*
This design option applies to gas-fired units. It involves using a power blower on the inlet or exit side of the unit to promote flow of the combustion products through the heat exchanger. This option permits higher combustion efficiency and reduces standby losses.

5) *Increased Insulation*
On outdoor units, jacket losses are reduced by adding insulation. Existing insulation is replaced with a denser fiberglass having the same thickness as the original insulation.

6) *Condensing Heat Exchanger*
The use of corrosion resistant heat exchangers and vent piping has led to furnaces boilers operating in the near condensation (84-88%) and condensing (90-96%) range.

7) *Additional Improvement Of Steady-State Efficiency*
Improvement in the steady-state efficiency, of a furnace can be achieved by 1) reducing the excess air for the combustion of the fuel, or 2) improving the effectiveness of the heat exchanger, that is, the heat transfer rate from the products of combustion to the heating medium (air or water).

8) *Two-Stage and Modulating Burners*
Another energy saving method is to operate for longer periods during the heating season at a reduced firing rate. This reduces the period during which off-cycle losses can occur and may increase the off period efficiency.

INTRODUCTION

The Energy Analysis Program at Lawrence Berkeley Laboratory (LBL) is responsible for managing the appliance standards analysis project. The major engineering effort required for the standards evaluation will involve analyzing the technologies necessary to increase appliance efficiency, and estimating the cost of the improvements. The specific objectives are: to determine appropriate product classes for efficiency standards, to estimate the efficiency of different product design options (for both existing technology and advanced designs), and to estimate the costs and prices of products that are increasingly efficient.

As a first step in the engineering analysis, DOE has requested that LBL prepare survey reports on energy efficient design options for the following products:

(1) Refrigerators and Refrigerator/Freezers;

(2) Freezers;

(3) Dishwashers;

(4) Clothes Dryers;

(5) Water Heaters;

(6) Room Air Conditioners;

(7) Home Heating Equipment (not including furnaces);

(8) Televisions Sets;

(9) Kitchen Ranges and Ovens;

(10) Clothes Washers;

(11) Humidifiers and Dehumidifiers;

(12) Central Air Conditioners (including heat pumps); and

(13) Furnaces.

LBL carried out the research and wrote the reports for products (3), (5), (7), (8), (10), (11), and (12). Survey reports for the six remaining products were written by Arthur D. Little under contract to LBL. Portions of the Arthur D. Little documents are incorporated into this document. This document identifies the changes that have taken place in the products since the original DOE analyses of them in the early 1980's, suggests possible revisions to product classes, and updates the selection of design options for cost/efficiency investigations. Future publications will discuss the change in efficiency brought about by each design change, and the cost of more efficient products.

In the original standards analysis, DOE segregated the basic models of product types into separate classes to which different energy efficiency standards would apply. DOE specified the

following criteria for segregating basic models into classes:

a. Basic models which have different primary energy sources, i.e., fossil fuel (oil or gas), or electricity, should be in different classes.

b. To the extent practicable consistent with the intent of the National Energy Conservation Policy Act, consumer products having different capacities or other performance-related features that affect efficiency and utility should remain available to consumers.

c. Separate classes should also ensure the availability of features providing utility when those features cause the energy efficiency of models on which they are found to be different from that of models without the features.

As part of the original DOE study, a technical and economic analysis was completed for each product, in order to assess the benefits and impacts of setting standards for minimum efficiencies at different levels. In this economic analysis the relationship between the cost of a consumer product and its efficiency was estimated, based on an examination of design options, for each product class. Combinations of design improvements were used to generate cost-efficiency relationships that become inputs to other analyses, which determine the national impact of setting standards at various efficiency levels. The design option analysis began with the selection of a baseline unit. The selection was initially based on information from industry sources and published data, and later was revised to reflect data obtained from DOE surveys. The baseline unit was defined as the unit with an efficiency, input, output, and size approximately equal to that of the most commonly produced unit in the baseline year. Once identified, each baseline unit was characterized in terms of the operational features which relate to its efficiency.

In the forthcoming engineering analysis, the baseline unit for each product class will be given an efficiency which is less than that of the shipment-weighted average for 1986. This will allow for the possibility of setting a standard below the shipment-weighted energy factor for some product classes. In the previous analysis, it was not possible to consider standards below the sales weighted energy factor since the baseline appliance, which had the lowest efficiency considered, had an efficiency approximately equal to the sales weighted energy factor. Using the same (1980) baseline, or one lower than the present sales weighted energy factor, will probably reduce the cost of the analysis and increase flexibility (e.g., backcast analyses can be performed).

Using engineering analysis and computer simulations, the efficiency improvements that would result from adding various design options to the baseline will be estimated. In the previous analysis, the design options were limited to those based on "available" technologies--defined as those technologies presently found in units available in the marketplace, at least in limited

production quantities. The 1985 Court of Appeals decision striking down the DOE standards action found that this approach limited the technologies considered without sufficient explanation, and failed to establish the maximum technologically feasible improvements as required by law. Therefore, in the forthcoming standards evaluation effort, DOE will assess additional design options such as those being used in foreign products and those in the prototype stage of development. A description of all design options presently identified and being considered for the evaluation of appliance standards follows. These design options are separated into two categories: those from the original analysis, and additional options not previously considered.

ENERGY CONSERVATION MEASURES FOR HOUSEHOLD REFRIGERATORS, REFRIGERATOR-FREEZERS AND FREEZERS

INTRODUCTION

An electric refrigerator is defined as a cabinet designed for the refrigerated storage of food at temperatures above 32 °F, and having a source of refrigeration that requires an electrical energy input only. It may include a compartment for freezing and storing food at temperatures below 32 °F, but does not provide a separate low-temperature compartment designed for the freezing and the long-term storage of food at temperatures below 8 °F. It has only one exterior door, but it may have interior doors or compartments.

An electric refrigerator-freezer is a cabinet which consists of two or more compartments with at least one of the compartments designed for the refrigerated storage of foods at temperatures above 32 °F and with at least one of the compartments designed for the freezing and the storage of frozen foods at temperatures of 8 °F or below; this second compartment may be adjustable by the user to a temperature of 0 °F or below. The source of refrigeration requires an electrical energy input only.

In this report, we identify the changes that have taken place in refrigerators, refrigerator/freezers and freezers since the original analysis in the early 1980's, suggest possible revisions to product classes, and update the selection of design options for cost/efficiency investigations.

PRODUCT CLASSES

In the original standards analysis, DOE segregated the basic models of product types into separate classes to which different energy efficiency standards would apply.

Refrigerators and Refrigerator-Freezers

For refrigerators and refrigerator-freezers, utility and performance considerations dictated separate product classes based on:

- Type of freezer defrost system (manual or automatic)
- Freezer compartment temperature
- Physical arrangement of freezer and refrigerator compartments
- Availability of through-the-door service features
- Compact size

Original Classes

The product classes chosen for the original standards analysis are listed in Table 1. DOE concluded that freezer compartment temperature, which is lower than that of just a refrigerator, constitutes additional utility for the consumer. Since lowering the freezer temperature increases heat leakage to the freezer and increases the energy consumption of the refrigeration system, DOE grouped refrigerators and refrigerator-freezers into separate product classes.

TABLE 1. PRODUCT CLASSES FOR REFRIGERATOR-FREEZERS AND REFRIGERATORS

1) Manual Defrost Refrigerator
2) Partial Automatic Defrost Refrigerator
3) Automatic Defrost Top Mount
4) Automatic Defrost Side-by-Side
5) Automatic Defrost Side-by-Side with Through-the-Door Service Features
6) Automatic Defrost Top Mount with Through-the-Door Service Features
7) Automatic Defrost Bottom Mount
8) Compact Refrigerator
9) *Manual Defrost Refrigerator-Freezer**
10) *Automatic Defrost All Refrigerator**
11) *Push Button Defrost Refrigerator-Freezer**
12) *Built-in Products, All Categories**

DOE also determined that automatic-defrost refrigeration products, which do not require any consumer action to accomplish freezer defrosting, provide utility to the consumer. Automatic-defrost products consume additional energy to circulate dry cold air, to melt frost when performing a defrost cycle, and to remove defrost heat from the cabinet in order to maintain compartment temperatures, therefore, DOE established separate classes for automatic-defrost products.

Automatic-defrost refrigerator-freezer configurations were further segregated according to the location of their freezer compartments. Top-mounted freezer units are by far the most common type of refrigerator-freezer sold. However, DOE determined that products with bottom-mount or side-mounted freezers provide utility to some consumers because the more frequently used fresh-food section is more accessible. Because of the basic engineering differences (discussed below) which affect energy consumption in these units, DOE proposed separate classes for automatic-defrost refrigerator-freezers with top-mounted, side-mounted, and bottom-mounted freezers.

*Items in italics are new classes under consideration.

Units with side-mounted freezers characteristically consume more energy than top-mounts because of increased door seal area and the proximity of the floor of the freezer to the hot motor compartment containing the compressor and condenser. Both factors increase cabinet heat gain. Units with bottom-mounted freezers require increased fan power to transport cold air from the evaporator to the top of the fresh-food compartment, and often require auxiliary heat in the crisper area to keep products stored there from freezing; they also experience higher cabinet heat loads from the motor compartment because of its proximity to the low-temperature freezer.

In addition, certain top-mounted and side-mounted refrigerator-freezer models have dispensing services which provide chilled liquids, water, and ice through the closed door. Since doors that contain dispensing equipment cannot be insulated as well as doors without this feature, and electric heaters may be required to prevent condensation from occurring on the dispenser hardware, heat leakage to the refrigerated space is greater than in models without dispensers. Consequently, models with through-the-door services characteristically consume more energy than other models. DOE determined that the convenience associated with such dispenser designs constitutes a distinct utility to the consumer, so separate classes were established for refrigerator-freezer designs that provide these services.

Finally, DOE established a separate class for compact refrigerators because they offer a particular utility to consumers but typically have a lower efficiency than standard-size products. As the volume of a cabinet decreases, its ratio of surface area to volume increases. Since heat transfer into the cabinet is related to surface area, units of smaller capacity with equivalent insulation and refrigeration system efficiency will have higher relative energy consumption than larger volume products. Compressors, fans and motors also become less efficient as their size decreases, which further decreases the overall efficiency of compact models.

New Classes

The original product classes are still relevant and useful for the reevaluation effort, because the industry has experienced evolutionary rather than revolutionary change since 1980. Imported products are built to appeal to the American consumer's desires and, as a result, generally fit into the product classes listed in Table 1.

However, several additional classes should be considered, namely:

1) Refrigerator-Freezer, Manual-Defrost,
2) All Refrigerator, Automatic-Defrost,
3) Built-in Products, All Categories, and
4) Push Button - Defrost Refrigerator-Freezer.

A manual defrost refrigerator-freezer includes a separate, below 8 °F freezer compartment. Current manual-defrost refrigerators typically do not; the all-refrigerator is an automatic-defrost unit without freezer. Some custom kitchens today use large separate refrigerators and freezer units and so a relatively small market has developed for refrigerators without an integral freezer. Custom kitchens also utilize built-in refrigeration products, i.e., those that are enclosed by cabinetry and may be of limited depth to match the kitchen countertop and cabinet depth.

The push-button (or semi-automatic-defrost) unit would permit the consumer to activate a defrost cycle only when necessary. Current automatic-defrost refrigerator-freezers use a timer to initiate defrost at a regular interval, whether there is frost buildup requiring defrost or not. Since the time between defrosts is specified by the most severe conditions (hot, humid weather), energy is wasted on unnecessary defrosts at other times of the year, or if the unit is located in dry ambient conditions. Demand-defrost is similar to push-button; in demand-defrost units, defrost is initiated only when necessary by automatic sensing of frost buildup (the user isn't involved). Either of these systems could save a significant amount of energy.

The need for a separate product class for any of the above designs should be investigated in the reevaluation effort, using the methodology developed in the original analysis. Additional classes are necessary if the products provide separate utility to the user and are sufficiently different in design from products in existing classes that they require different design option analyses and proposed standard levels. Since standards cannot be set for products for which there are no DOE test procedures, demand-defrost units would currently be exempt from standards.

Freezers

Original Classes

For freezers, utility and performance considerations dictated five separate product classes. Three of these result from the:

- type of defrost system (manual or automatic), and
- Configuration (chest or upright)

as discussed below. Two result from the inherent lower efficiency of compact units. The product classes chosen for the original standards analysis are listed in Table 2.

TABLE 2. PRODUCT CLASSES FOR FREEZERS

1) Chest, Manual Defrost
2) Upright, Manual Defrost
3) Upright, Automatic Defrost
4) Compact Upright
5) Compact Chest

The configuration of the unit (i.e., chest or upright) provides utility to the customer but also affects efficiency. Upright freezers offer greater accessibility to freezer contents and more efficient use of floor space than chest freezers. However they consume more energy in actual home usage conditions than chest freezers of equivalent design, because more cold air leaks out of the upright unit each time the door is opened. Consequently, DOE has grouped these products into separate classes.

Another performance-related feature that affects utility and efficiency is the type of defrost system. Automatic-defrost units do not require any consumer action to accomplish defrosting, and thus provide the consumer with a utility not provided by manual-defrost units. Automatic-defrost units are less efficient than manual-defrost units because of the additional energy required to circulate cold dry air, melt the accumulated frost, and remove the defrost heat. Since there are no chest freezers in production that offer the automatic-defrost feature, a separate class was established only for automatic defrost upright freezers. DOE designated two separate classes for compact chest and upright freezers. These products offer a particular utility to the consumer, but are less efficient than standard freezers for the same reasons as compact refrigerators.

New Classes

At this time, no new freezer classes are being considered for the forthcoming engineering analysis.

DESIGN OPTIONS

Industry studies* have shown that the efficiency of refrigeration products has steadily increased since the original DOE analysis. Most of the design options in Tables 3 and 4 can be found on units currently in the marketplace. One manufacturer reports that 85% of the top mount, automatic-defrost products offered have foamed freezer doors and some also have foamed refrigerator doors. Eighty percent of upright freezers have foamed doors.

*For example see: Docket No. 84-AES-1, "Statement of the Association of Home Appliance Manufacturers Opposing Proposed Standards for Refrigerators and Refrigerator-Freezers" California Energy Commission, Sacramento, CA, September 20, 1984.

TABLE 3. REFRIGERATOR AND REFRIGERATOR-FREEZER DESIGN OPTIONS ORIGINAL DOE ANALYSIS

1) *Foam Insulation Substitution in Doors*

Fiberglass insulation is replaced with polyurethane foam insulation. Since polyurethane foam has a thermal conductivity lower than that of fiberglass, this option reduces total cabinet heat leakage.

2) *Increased Door Insulation Thickness*

Foam door insulation is increased to a nominal thickness of 2 inches to further reduce heat leakage.

3) *High-Efficiency Compressor Substitution*

A high-efficiency compressor replaces a conventional design.

4) *Double Door Gasket*

An additional inner door seal gasket reduces heat leakage and air infiltration through the door.

5) *Anti-Sweat Heater Switch*

Cabinet heaters prevent condensation on the cabinet exterior in high humidity. A switch is installed, which can be used in a dry environment to shut off the heaters. Energy savings are realized by eliminating both the heater power consumption and the heat that flows into the cold space from these heaters, which must be removed by the refrigeration system. In baseline units with a hot gas loop, this option includes replacing this loop with electric resistance wire.

6) *Increased Cabinet Insulation Thickness*

Foam cabinet insulation is increased to a nominal 2 inches to decrease heat leakage.

7) *Reduce Heat Load of Through-the-Door Feature*

Improved insulation can be used to decrease the heat leakage and additional power consumption attributable to the through-the-door service feature (ice, water, etc.).

8) *Increased Evaporator Surface Area*

Increased heat exchanger surface area in the evaporator produces more efficient operation of the refrigeration system.

9) *Hybrid Evaporator*

The use of separate evaporators in the refrigerator and freezer compartments of a refrigerator-freezer increases performance by reducing defrost requirements, fan power consumption, and door gasket air leakage.

TABLE 4.
FREEZER DESIGN OPTIONS - ORIGINAL DOE ANALYSIS

1) *Foam Insulation Substitution in Cabinet*

The 2-1/2 inch thick fiberglass cabinet insulation is replaced with 2-1/2 inches of polyurethane foam. The lower conductivity of foam reduces cabinet heat leakage.

2) *Foam Insulation Substitution in Door*

Fiberglass insulation in the freezer door is replaced with polyurethane foam insulation. Since polyurethane foam has a thermal conductivity lower than that of fiberglass, this option reduces total cabinet heat leakage.

3) *Increased Cabinet Insulation Thickness*

Foam cabinet insulation is increased to a nominal 2-1/2 inches to further decrease heat leakage (chest freezer only).

4) *Increase Door Insulation Thickness*

Foam door insulation is increased to a nominal thickness of 2 inches to further reduce heat leakage (chest freezer only).

5) *High-Efficiency Compressor Substitution*

A high-efficiency compressor replaces a conventional design.

Door thicknesses have been increased to at least 1.5 inches. Compressors with energy efficiency ratio (EER) ratings of 4.3 to 4.5 are being used and most products have compressors with EER's of at least 3.9. Anti-sweat heater switches are used in all top-mount, automatic-defrost units. An improved door gasket has been developed which provides some of the benefits of double gaskets without the perceived problems (freezing of trapped moisture which can jam the door shut). All new designs have at least 2 inches of foam insulation around the freezer and all freezers have foamed cabinets. Over 40% of the top-mount, automatic-defrost units have increased evaporator surface area for improved efficiency and performance.

Options from Previous Analysis

The design options that were used in the original analysis (listed in Tables 3 and 4) are, on the whole, still viable and are common in current products. However, each of these options will be reanalyzed and, in some cases, changes will be made in the analysis to incorporate new product designs and/or new knowledge.

For example, under the anti-sweat heater switch option, reduced wattage of heaters will be considered in addition to the use of the switch alone. Greater thicknesses of insulation, when

appropriate, will also be considered. Manufacturers, in some cases, have not achieved the total savings predicted, but see no real obstacles for further development. For example, the 5.0 EER compressor used in the DOE analysis is not yet available (4.6 EER is now offered) but will be, although possibly not in all sizes. The insulation thicknesses in cabinets and doors have been increased, but not universally to the levels analyzed by DOE.

Only two of the design options have raised significant concern. The double door gasket could cause problems in the field due to freezing of trapped moisture which can jam the door shut. Development and substantial in-service testing will be necessary to improve its performance. Additionally, improvements to single gaskets are making the energy saving potential of the two-gasket concept smaller.

The hybrid evaporator has been shown to be a substantial energy saver in a commercially available top-mount, automatic-defrost refrigerator-freezer. However, some manufacturers believe the concept is not a realistic option for saving energy in all models. Under certain operating conditions and for some uses, its performance differs from traditional automatic defrost designs. Excess moisture and inadequate pull-down (refrigerator cooling capability) were observed in some field applications.

Additional Options

In the original analysis, a double gasket was considered a design option for refrigerator/freezers only. In the forthcoming analysis, improved and double gaskets will be added to the list of design options for freezers. A list of additional technology options for refrigerators, refrigerator-freezers, and freezers follows:

a. Adaptive Defrost Controls

"Smart" controls, which adjust the interval between defrost cycles, could save significant energy depending on the refrigerator model, and usage, and the ambient conditions in which the appliance is located. These controls can be of several types. For example some "learn" how often a defrost cycle is needed from the time required to defrost the unit previously. Others sense the frost buildup on the evaporator coil directly. Several prototypes have been developed and demonstrated; therefore, commercial introduction could occur quickly.

b. Higher-Efficiency Compressors

Compressor efficiency has been steadily increasing. Whereas a typical top mount, automatic defrost unit had a compressor with a 3.2 EER in 1980, today that value is 3.9 or higher. An EER of 4.6 is now commercially available and a 5.0 EER unit is expected in the near future. A 5.0 EER compressor has been developed and field tested under DOE sponsorship.

Since 1980, the compressor industry has changed significantly. Most compressors in the size range of interest are now produced abroad. The reevaluation effort will therefore need to study foreign technology and production techniques in order to generate accurate cost-efficiency data for the standards analysis.

c. Fan and Fan Motor Improvement

Typical evaporator and condenser fan motors today consume 10-16 Watts. New technologies, such as dry-film capacitor motors, could reduce consumption to 5-8 Watts in the near term. However, cost is expected to be high, and reliability is unproven. The 50% savings potential, although dramatic, is small in absolute terms when compared to compressor and defrost power consumption. More efficient fan designs, to improve fan mechanical efficiency, will also be studied.

d. Enhanced Heat Transfer Surfaces

As mentioned previously, heat transfer area has been added to the evaporator in some models to increase efficiency. Recently, there have been gains made in heat transfer performance for finned tube air conditioning coils resulting from techniques that involve increasing turbulence on both the air and refrigerant side of the coil. Measurable gains in the rate of heat transfer have been achieved for air conditioner coils; similar gains might be achieved with refrigerator coils. Air velocity in refrigerators is much lower than in air conditioners, frosting defeats any special fan configurations, and the DOE energy tests are conducted in a cycling mode of operation. All of these reduce gains (as measured by the test procedure) that result from heat transfer enhancement.

e. Mixed Refrigerants

Theoretical studies of mixed refrigerants have suggested they could improve efficiency. However, more recent studies, by W.F. Stoecker and others, with actual systems have shown rather conclusively that, in practical terms, no demonstrable improvement in performance results from the use of mixed refrigerants in refrigerator-freezers. Changes made to the refrigeration system to exploit the advantages of mixed refrigerants also improve performance with a standard single refrigerant.

In products such as heat pumps, mixed refrigerants have been used successfully for operations such as capacity modulation with a single speed compressor. Analytical studies may in time discover new refrigerant mixtures or techniques to realize the theoretical, thermodynamic advantages in refrigerators.

f. Fluid Control Valves

Current refrigerator products use a capillary tube to control refrigerant flow into the evaporator. The capillary tube is inexpensive and trouble-free, and can be tuned to provide efficient operation at the design point. At off-design, especially high load conditions, an automatic, adjustable expansion valve can provide better performance.

The thermostatic expansion valve (TXV) is widely used in air conditioners because of the variability in design conditions. TXV's would provide better performance for refrigerators and freezers at off-design conditions, but the overall impact on energy consumption has been shown to be small. TXV's are also more expensive, and less reliable than capillary tubes. For products with an average life of 15 years or more, manufacturers might be reluctant to use them in the sealed refrigeration system. The reevaluation effort, however, should review modern developments in TXV's (such as electronic control) and their associated energy savings possibilities. The current test procedure would have to be modified to reflect the savings possibilities.

g. Improved Foam

Lower conductivity polyurethane foam for cabinet and door insulation would decrease cabinet heat leakage and the energy required to maintain the refrigerator or freezer at its proper temperature. The conductivity of foam is primarily determined by the trapped gas in the plastic foam cells. The fluorocarbon gases currently used are very effective insulators. Therefore the improvements will relate to changes in the cell structure and the solid conduction of the foam walls and will be relatively small. The resulting increases in overall product energy efficiency are also expected to be quite small.

h. Evacuated Insulation Panels

The gas-filled plastic foams used in current products are quite efficient insulators. Significant decreases in heat leakage require radically different approaches. One approach would use evacuated panels in the large planar walls of the cabinet so that heat transfer through the panels would be negligible (except for edge conduction, etc.).

Evacuated panels (filled with low-conductivity powders that prevent collapse) are foamed in place between the cabinet liner and wrapper to decrease the heat leakage and energy required to maintain the cabinet at low temperature. However, there are, at present, some unresolved technical questions related to these panels, such as long-term vacuum integrity, panel fabrication and testing, and refrigerator assembly. The time required for U.S. manufacturers to implement this option on a large scale is unknown.

Apparently one foreign manufacturer has introduced a limited production model with evacuated panel insulation. The reevaluation effort must therefore give serious consideration to this

design option as a significant energy saving option suitable for commercial introduction, or at least as a candidate for the maximum technologically feasible unit.

i. Two-Compressor System

Refrigerator/freezers can operate more efficiently with separate refrigeration systems for the refrigerator and freezer compartments. A higher evaporator temperature in the fresh food refrigerator compartment results in a higher efficiency. Another advantage of a two compressor system is a reduced demand for defrosting. Less moisture condenses on the cold surfaces of the fresh food section when cold air from the freezer section does not have to be circulated through the fresh food compartment. Additionally, with this configuration, defrosting in the fresh food section can be accomplished by leaving the compressor turned off until the evaporator reaches a temperature above freezing. This does not require electricity, nor does it add to the heat load. Some European manufacturers and one small U.S. firm are now building two-compressor systems[1].

j. Use of Natural Convection Currents

If fans can be eliminated, refrigeration system efficiency is increased, because fans require electricity to run, and electrical energy to remove the heat that fans produce. In some two-compressor refrigerator/freezers, natural convection currents have been used in lieu of fans.

k. Location of Compressors and Condensers

Top-mounted compressors and condensers can cool more efficiently because they can run cooler than bottom-mounted ones. In this configuration, as opposed to the traditional bottom mounted compressor, heat tends to be more readily convected away from the refrigeration system. Additionally, most of the heat generated by these components does not re-enter the cabinet.

REFERENCES

1. P. Pedersen, J. Schjaer-Jacobsen, and J. Norgard, "Reducing Electricity Consumption in an American Type Combined Refrigerator/Freezer", Proceedings of 37th Annual International Appliance Technology Conference, May 1986, Purdue University, West Lafayette, Indiana.

ENERGY CONSERVATION MEASURES FOR DISHWASHERS

INTRODUCTION

A dishwasher is a cabinet-like appliance which, with the aid of water and detergent, washes, rinses, and dries (when a drying process is included) dishware, glassware, eating utensils, and most cooking utensils by chemical, mechanical and/or electrical means, and discharges waste water to the plumbing drainage system. Dishwashers use electrical energy to run a motor, fan, and heaters. A supplemental heater is sometimes used to assure availability of 140°F water for wash cycles, and a drying heater and fan are used during the drying cycle. They also require hot water, which is provided by an external water heater. Most of the energy used by a dishwasher is for heating water. Dishwasher efficiency is expressed in terms of loads per kWh of total energy used. The dishes are washed, rinsed, and dried inside an insulated cabinet. A pump sprays water through one or more wash arms onto the dishes and other dirty objects. A motor is used to rotate the spray arm and circulate the water throughout the dishwashing compartment. Several wash and rinse cycles are completed before the drying element is used to dry the contents of the dishwasher. A drain pump is used to remove the water from the chamber.

PRODUCT CLASSES

Original Classes

Three classes of dishwashers were established by DOE (see Table 5). Compact dishwashers use less water and energy than standard size dishwashers. Standard size dishwashers have an exterior width greater than or equal to 22 inches, compacts have an exterior width less than 22 inches, and water-heating dishwashers have the ability to heat incoming hot water. Water-heating dishwashers allow for lower water heater thermostat settings since they can heat water to a temperature of 140°F or higher.

TABLE 5. PRODUCT CLASSES FOR DISHWASHERS

1) Compact Dishwasher
2) Standard Dishwasher
3) Water heating Dishwasher
4) *Water Heating Dishwasher, Compact (115V)**
5) *Water Heating Dishwasher, Standard (115V)**
6) *Water Heating Dishwasher, Compact (230V)**
7) *Water Heating Dishwasher, Standard (230V)**

*Items in italics are new classes under consideration.

New Classes

It has been suggested that water heating dishwashers be divided into four classes: compact and standard capacity water heating dishwashers, each with 115V and 230V inputs. The justification is that standard-size water heating dishwashers use more energy than compact models, and that water is heated more rapidly in a 230V dishwasher with a cold water inlet than in a 115V dishwasher with a warm water inlet. If these four classes are added, then class 3 will be eliminated.

DESIGN OPTIONS

Options from Previous Analysis

Most of the energy used in dishwashing goes for water heating. Some energy is also needed to spray water and for the power dry cycle (when that option is used). Potential design options for reduction of energy use are listed below:

1) Improved food filters
2) Improved spray arm geometry
3) Improved fill control
4) Modified sump geometry
5) Optional power dry
6) Reduced inlet water temperature (for water-heating dishwashers)
7) Improved motor efficiency
8) Increased insulation

Food filters remove food particles from the water during the wash and rinse cycles and thus keep food from redepositing on the dishes. If filters were improved to remove sufficient food particles, the duration and frequency of the rinse and wash cycles might be reduced. This would reduce hot water use. The performance of the dishwasher must not, however, be diminished by the use of less hot water for rinsing and washing.

Spray arms are usually located in the top and bottom of a dishwasher. They rotate and spray water under pressure on the contents of the upper and lower shelves. If the spray arms could be designed to more efficiently remove food particles from the dishwasher contents, then a dishwasher design using less hot water and less energy to perform its cleaning function would be possible.

The amount of water used for each cycle can be reduced by a change in the geometry of the sump and by a modification of the fill control. The configuration of the bottom of the dishwasher trap would allow for a larger sump and eliminate cavitation of the pump at low water levels. The fill control must be modified to admit a lower volume of water.

After dishes are washed and rinsed, an electric heating element is used to dry the dishwasher contents. If dishes were air dried rather than through electrical resistance heating, electrical energy could be saved. About 8% of the energy used by a dishwasher could be saved with this air dry option[1]. The elimination of the heater will increase the drying time relative to a dishwasher using a power dry option.

A reduction in the inlet water temperature from 140°F to 120°F would save about 18% of total energy used by a dishwasher[2]. It would be necessary to find a detergent that would effectively remove food particles and fats from dishes when the water temperature is at 120°F. At the present time, many manufacturers feel that 140°F water is needed to clean dishes properly. However, tests conducted by Kaneko and Compton showed that, with 100°F water, four of six brand-name detergents performed with good to excellent results[3]. Additional detergent is usually needed when lower water temperatures are used. Some dishwashers operate with 120°F inlet water temperature and use a supplemental heater to raise the water temperature to 140°F. This allows the water heater thermostat setting to be lowered from 140°F to 120°F. Standby losses are significantly lowered and the water heater energy factor is improved. This water-heating dishwasher will use more electrical energy than a standard dishwasher, but the total energy use of the dishwasher and water heater will be less. Water-heating dishwashers form a separate class of dishwashers because the water-heating feature is a utility feature that affects energy consumption.

The electric motor consumes about 8% of the energy used in a typical dishwasher. Dishwashers typically use split phase motors because of the low torque requirement and constant starting current condition in these appliances. A capacitor-type electric motor is more efficient than a split phase motor. The capacitor-type electric motor increases the power factor, and, therefore, reduces heating losses in the stator[4]. An electric motor efficiency improvement from about 45% to 60% should be possible. The overall effect of such an improvement in electric motor efficiency would be an approximately 3% decrease in dishwasher energy use.

Dishwashers generally have some insulation to reduce noise levels. Additional insulation around the tub will decrease heat losses further. However, the marginal benefit for additional insulation is small. A reduction in heat loss would allow use of lower temperature water. A reduction of 5°F in inlet water temperature reduces energy consumption by about 6.5%[5]. The drying efficiency is also improved when insulation is added.

Additional Options

No additional options have been identified at this time.

REFERENCES

1. "Energy Efficiency Program For Clothes Washers, Clothes Dryers, and Dishwashers", Science Applications Inc., La Jolla CA, November, 1977.

2. Ibid.

3. T. Kaneko and J. Compton, "Low Temperature Home Machine Dishwashing" Proceedings of the Conference on Home Appliance Technology for Energy Conservation, Purdue University, February, 1977.

4. "Classification and Evaluation of Electric Motors and Pumps", U.S. Department of Energy, DOE/TIC-11339, September, 1980.

5. "Energy Efficiency Program For Clothes Washers, Clothes Dryers, and Dishwashers", Science Applications Inc., La Jolla CA, November 1977.

ENERGY CONSERVATION MEASURES FOR HOUSEHOLD CLOTHES DRYERS

INTRODUCTION

A clothes dryer is a cabinet-like appliance designed to dry fabrics in a tumble-type drum with forced-air circulation. The heat source may be either electricity or natural gas. Compact clothes dryers have a drum capacity of less than 4.4 ft^3, and standard clothes dryers have a capacity of 4.4 ft^3 or greater.

PRODUCT CLASSES

Original Classes

DOE originally specified four classes (see Table 6) of clothes dryers. These product classes were distinguished by different energy sources and by performance-related features. Gas and electricity are the energy sources. The performance-related features include drum capacity and application voltage.

TABLE 6. PRODUCT CLASSES FOR DRYERS

1) Electric, Standard
2) Electric, Compact 120V
3) Gas
4) Electric, Compact 240V
5) *Gas, Standard**
6) *Gas, Compact**

Class distinctions were considered, but not adopted, based on the type of control used to end the drying cycle. The three types of control systems are: (1) a present timer control, (2) an automatic temperature-sensing control, and (3) an automatic moisture-sensing control. The energy efficiency for a dryer is related to these controls. However, product classes based on these controls were not established because the test procedure accounts for effects of controls with a field use factor.

Product classes were established for electric dryers based on drum capacity and application voltage. The test procedures specify two sizes of drum capacity. These are: (1) compact, electric dryers with a drum capacity of less than 4.4 cubic feet and (2) standard electric dryers with a

*Items in italics are new classes under consideration.

drum capacity of 4.4 cubic feet or more. The compact dryers tend to be less energy-efficient than the standard dryers. As the compact dryers provide added utility--they are suitable for small spaces--a separate class was established for them. Therefore, the two product classes for electrical dryers, based on drum capacity are (1) compact electric dryers and (2) standard electric dryers.

Separate product classes were established for compact electric dyers, based on appliance voltage. The 120-volt dryer tends to dry clothes at lower temperatures and for longer time periods than the 240-volt dryer. In general, the 120-volt dryer is more energy-efficient. Many consumers feel that the 120-volt dryer has greater utility because it can be installed anywhere, while the 240-volt dryer must be near a 240-volt outlet. Other consumers feel that the 240-volt dryer has greater utility because it dries clothes faster. Since the 240-volt compact electric dryer is less energy-efficient and provides added utility to some consumers, separate product classes were established for compact dryers.

A clothesdryer's efficiency is related to its drum capacity. Larger drums have a higher thermal capacity and, therefore, require more energy to come up to temperature than smaller drums. Since the test procedure uses a fixed load size, independent of drum size, larger capacity dryers use more energy per pound of clothes, as measured by the test procedure. Second, the air flow through the tumbling clothes is affected by the ratio of the load size to the drum size. If small loads are used in large drums, the air tends to bypass the clothes, increasing the energy required to dry the test loads. Therefore, using the same test load for all sizes of standard dryers means smaller capacity standard dryers have higher energy efficiency (as measured by the test procedure) than large capacity standard dryers.

Relationships between efficiency and capacity were derived from data submitted by individual manufacturers and from industry-wide survey data. Testimony submitted by industry indicated that the same relationship would apply to gas and electric units. Data from these sources all indicated a distinct relationship between volume and efficiency for standard size electric units. The same slope was used for electric and gas units. For compact units, the available data were inconclusive about the relationship between efficiency and volume. In some cases, a positive slope and in others a negative slope was indicated. In any case, the slope was small. Therefore, the standard for compact dryers was assumed to be independent of volume.

New Classes

Since the previous analysis, there have been only a few changes in units on the market. Electronic controls are used more often now. In some cases, stacked washers and dryers are using common control systems. However, there is no evidence to suggest that the changes have affected the efficiency of the product and therefore they do not warrant any additional product

classes. The trend toward offering downsized appliances for apartments and condominiums, and toward stackable configurations has led to an increase in the number of compact gas dryers. This increase may create the need for a new product class.

DESIGN OPTIONS

Current data indicate that the number of units shipped with automatic termination using temperature or moisture sensing has increased significantly in the last few years. One manufacturer says only 16% of the units shipped in 1985 do not have some form of automatic termination. Thus, the baseline energy efficiency should be increased accordingly. This will reduce energy saving estimates for this class of appliances.

FROM PREVIOUS ANALYSIS

In the previous analyses, three design options were evaluated for improving the efficiency of clothes dryers. These were:

1) *Automatic termination by moisture sensing:*

   This design option reduces energy used by ensuring that a dryer turns off as soon as all the moisture is removed from clothes. The moisture content of the air exiting from the dryer is checked by a sensor, which determines shutoff. The actual savings depends on consumer use patterns.

2) *Automatic termination by temperature sensing:*

   This design option reduces energy consumption in the same way that moisture sensing does. However, it relies on a rise in the temperature of the exiting air to terminate the cycle. Since this temperature rise occurs after all the moisture has been removed, temperature-sensing dryers don't turn off as soon as moisture sensing dryers, so temperature sensors don't save as much energy. As with the moisture sensor, the actual savings depends on consumer use patterns.

3) *Insulation:*

   During the drying cycle, some areas of the dryer cabinet are at temperatures above room temperatures. This results in standby losses, which can be reduced by insulation.

These design options are still viable, although manufacturers question the energy saving estimates associated with the use of increased insulation. To date, no manufacturers have adopted this option. The options to terminate the drying cycle automatically are now in

widespread use.

ADDITIONAL DESIGN OPTIONS

Additional design options suggested for residential clothes dryers are:

1) *Condenser*

   In this option, a heat exchanger is used to condense moisture out of the air stream leaving the dryer. The "dried" air is then recirculated, which saves some of the energy that would have been needed to heat "new" air from ambient to drying temperature. This type of dryer is currently available in Europe and Japan. This option is only applicable to electric dryers.

2) *Recycle Heat Exchange*

   With this design option, a portion of the exhaust air stream is reintroduced at the dryer air inlet. Thus, some of the energy in the exhaust stream is recovered and efficiency is increased. This option can be used in gas and electric dryers.

3) *Inlet Air Preheat*

   A heat exchanger is used in this option to recover exhaust energy and use it to preheat inlet air. This is an open cycle system (as opposed to the closed cycle condenser option) and can be used in gas and electric units.

4) *Modified Operating Conditions*

   Reducing air flow and/or heat input rate changes the efficiency of the drying process. Manufacturers have currently selected operating points which match the dryer cycle time to the washer time for enhanced consumer utility. This is not necessarily the optimum dryer operation from an efficiency standpoint.

5) *Heat Pump*

   An electric heat pump can be used to remove heat from the exhaust stream and return the heat to the dryer at high temperature.

6) *Microwave Dryer*

   Microwaves are absorbed by water molecules. Therefore, damp clothes can be dried if they absorb electromagnetic energy, which is converted to heat energy, causing the water to evaporate. At least one U.S. manufacturer is working on this concept[1].

REFERENCES

1. H. Geller, "Energy Efficient Appliances: 1986 Update", Proceedings of the ACEEE 1986 Summer Study on Energy Efficiency in Buildings, August, 1986, American Council for an Energy-Efficient Economy, 1001 Connecticut Avenue, N.W., Washington, D.C. 20036.

ENERGY CONSERVATION MEASURES FOR RESIDENTIAL WATER HEATERS

INTRODUCTION

Residential water heaters operating at a temperature of less than 180 °F and using gas, oil, or electricity to heat water are all included in this product type. Water heaters supply hot water for many domestic uses including dish and clothes washing, and bathing and showering. Some water heaters store hot water for later use and others supply hot water on demand.

PRODUCT CLASSES

Original Classes

There are at least six classes of water heaters that should be considered in the standards setting process. These are shown in Table 7 below.

TABLE 7. PRODUCT CLASSES FOR WATER HEATERS

1) gas-fired (includes propane) storage type water heaters, less than or equal to 100-gallon capacity
2) electric resistance storage type water heaters, less than or equal to 120-gallon capacity
3) oil-fired storage type water heaters, less than or equal to 50-gallon capacity
4) *electric heat pump water heaters*
5) *gas instantaneous water heaters*
6) *electric instantaneous water heaters*

The first two classes were included in the previous standards analysis. Oil-fired water heaters were excluded from the standards setting process in the past because there were relatively few sales and because of a potential adverse impact on manufacturers. Oil-fired water heaters presently account for approximately 0.5% of total annual water heater sales (7 million)[1]. There are few sales of the latter three water heater classes compared to gas and electric storage type water heaters.

*Items in italics are new classifications under consideration.

New Classes

The latter three product classes are now not included in the DOE test procedure for water heaters; however, this will likely change in the near future. Recently a number of manufacturers have introduced integrated space heating and water heating appliances. These appliances use one oil-fired or gas-fired burner or one electrically driven heat pump to supply both space heating and hot water. Presently there is no test procedure to rate the water heating energy efficiency of integrated appliances.

There is a large potential for energy conservation through the use of heat recovery from residential appliances. Waste heat from the operation of air conditioners, refrigerators, and other appliances could be used to preheat incoming water before it enters the water heater. A device known as a desuperheater can be used to remove heat from the refrigerant in an air conditioner rather than releasing it to the outdoors. In the cooling season, the desuperheater (which is a heat exchanger mounted on an air conditioner) can provide much of the hot water needs to a household requiring daily cooling. Some tightly built houses are using air-to-air heat exchangers and exhaust heat recovery devices. A heat pump can be used to pump heat from the source (exhaust air stream) to the hot water storage tank. Test procedures are not available to measure the efficiencies of water heaters employing heat recovery. However, as the penetration of desuperheaters and other heat recovery devices increases, it may become desirable to establish additional classes of water heaters and corresponding test procedures.

Heat pump water heaters

Heat pump water heaters can be purchased with a storage tank or as add-on units where storage tanks already exist. Although the efficiency of heat pump water heaters without a tank cannot be improved by increasing the tank insulation, increased insulation is a viable efficiency improvement option for water heaters with a tank. Therefore, separate classes have been established for these two kinds of heat pump water heaters.

Heat pump water heaters move heat from the surrounding air to hot water contained in a storage tank. Electrical energy is required to reverse the natural flow of heat energy from warm to cold bodies; heat pump water heaters use a vapor-compression cycle, similar to the one used by refrigerators and air conditioners. A refrigerant is used to move heat from the source (usually the surrounding air) to a sink (the stored water). The refrigerant picks up heat from the surrounding air in an evaporator and gives it up when it condenses. The condenser is located in the storage tank. The liquid refrigerant then passes through an expansion device where its temperature and pressure are reduced. The cycle is repeated after the refrigerant is returned to the evaporator.

Heat pump water heaters cool their surroundings as they pump heat from their surroundings to the storage tank. If they are located in conditioned spaces, their operation in summer will reduce cooling loads and air conditioner use (if any is required in the climate considered). In the winter, heating loads will be increased and the heating system will use more energy. A field test indicated that heat pumps located in basements did not substantially affect space heating loads[2].

At the present time, there is no DOE test procedure for heat pump water heaters; however, a "simulated use" test method should be proposed this year (1986). There is, however, a test procedure developed by the Gas Appliance Manufacturers Association (GAMA) for heat pump water heaters. The energy factors listed in reference 2 were obtained from the GAMA test procedure. The maximum energy factor for a 52-gallon capacity heat pump water heater (with tank) was 3.4 in 1985. The range of values for all sizes of water heaters was from 2.5 to 3.4. For heat pump water heaters without tanks, the energy factor ranged from 2.0 to 2.9. These maximums will probably decrease with the "simulated use" test method. Field tests of heat pump water heaters in various climates resulted in an average energy factor of 2.0 and a range from 1.75 to 2.50[3]. The research report did not indicate whether these were add-on units or integral units with tanks. Heat pump water heaters are being marketed by more than 15 manufacturers and many utilities are evaluating their use in field programs. In 1985, only about 10,000 heat pump water heaters were delivered to retailers. This compares to 3.48 million residential electric resistance storage type water heaters shipped for that year.

Instantaneous water heaters

Instantaneous or demand type water heaters are different from storage type water heaters because they do not use tanks for hot water storage. Instead, they heat water as needed or demanded. Standby losses are significantly reduced, which potentially increases the energy efficiency of this class of water heaters compared to others. After a draw is completed, however, there is always some volume of water remaining in the heat exchanger that will lose heat to the surroundings during standby. The heat energy source can be either electricity or natural gas. If it is the latter, a vent must be provided to exhaust the products of combustion. Additional standby losses will result from losses up the vent.

Instantaneous water heaters are activated by a flow sensor. When water flow is sensed, the burner or heating element is turned on. Heat energy is transferred to the water through a heat exchanger which is located close to the burner. If the water flow rate gets too high, the heater may not be able to provide hot water at the desired temperature. Flow rate and outlet temperature are dependent on each other.

There is presently no DOE test procedure established for instantaneous type water heaters. However, a proposal that would include a test method for instantaneous water heaters should be

published this year (1986). Shipment figures are not available but are believed to be no greater than for heat pump water heaters. Energy factor values are not available for instantaneous water heaters presently being manufactured. However, the electric instantaneous type water heaters should be almost 100% efficient. Newly manufactured gas-fired instantaneous type water heaters (with pilot lights) are at least 75% efficient. These estimates exclude heat lost by the small volume of water that remains in the water heater after each use.

DESIGN OPTIONS

Options From Previous Analysis

In the previous water heater energy analysis, the three design options studied were: improved insulation, heat traps, and improved baffling coupled with a reduced main burner input rate. The first two are discussed immediately below and the third (a combination of two options) is discussed in two parts, somewhat later.

Jacket Insulation

Standby losses are significant for gas-fired, oil-fired and electric water heaters. We estimated that 8-15% of the total energy consumption of gas-fired water heaters is due to losses through the jacket. This range was estimated by using the test procedure equations, values for S and E_r found in the Directory of Certified Water Heater Efficiency Ratings[4], and conductivity values for fiberglass and polyurethane insulation. For oil-fired water heaters, jacket losses also range from 8 to 15% of total input energy. For electric resistance storage type water heaters, jacket losses range from 10 to 23% of total input energy. This heat loss can be reduced by increasing the R-value of existing insulation or by adding insulation to previously uninsulated areas of the tank. Typical water heaters use fiberglass insulation and more efficient models use polyurethane foam insulation. Insulation can be placed around the sides, top, and bottom of the water heater tank. There are two ways of increasing the R-value of the jacket insulation. One is to use denser fiberglass insulation. For a mean temperature of 112°F, the thermal resistivity of fiberglass ranges from 2.84 hr.ft^2.°F /Btu.in. for a density of 1/2 pound per cubic foot to 4.0 hr.ft^2.°F/Btu.in. for a density of 2 pounds per cubic foot[5]. Polyurethane foam insulation has a thermal resistivity* of 6.25 hr.ft^2.°F/Btu.in. and is, therefore, capable of reducing heat losses beyond the ability of the densest fiberglass insulation[6]. The maximum thickness of insulation that is practical for the sides of a water heater is a ring of 4.0 inches width. This allows a crated water heater to fit through a 32-inch doorway and neglects cost-effectiveness considerations .

* The thermal resistivity is for a mean temperature of 75°F.

Some estimates of energy savings resulting from the use of increased insulation are as follows[7]:

(1) Increasing fiberglass insulation by 2.5 inches (from 1.5 to 4.0 in) on a 42-gallon electric water heater resulted in an experimentally determined reduction in energy use of 10.9%.

(2) Increasing polyurethane insulation from 1.0 to 3.75 inches resulted in a theoretically determined 11% reduction in annual energy use for a gas-fired water heater.

Heat traps (Anti-convection valves)

In storage type water heaters, hot water in the tank rises through the hot and cold water feed lines. As it cools it becomes more dense than its surroundings and sinks. It is replaced by more buoyant hot water. This convective loop is a source of heat loss from the tank to the feed line pipes above and eventually to the surrounding air. The convective loop can be broken by one-way valves (thermal traps) or by placing loops in the feed lines. Such valves are commercially available with gravity-activated ball poppets to restrict the convective flow of water in both inlet and outlet pipes. Two papers report very different energy savings from the use of heat traps[3,8]. The first claims about 65 kWh/yr (1% reduction) for a 90°F temperature differential (storage water temperature - ambient temperature) and the second about 300 kWh/yr (4.8% reduction) for the average of several studies. The temperature differential was not reported in the second paper. The DOE test procedure allows a credit of 245 kWh/yr for the use of two heat traps installed as an integral part of the water heater[9]. DOE is proposing that a laboratory test be used to determine the appropriate credit.

Additional Design Options

For gas-fired and oil-fired water heaters, the design options to be discussed are:

1) Reduction of heat leaks from fittings,
2) Reduced pilot light input rate,
3) Use of automatic ignition with a flue damper,
4) Elimination of central flue and indirect heating of water,
5) Increased flue baffling with forced draft,
6) Use of multiple flues,
7) Use of a submerged combustion chamber,
8) Use of pulsed combustion,

9) Condensation of flue gases.

This will be followed by a discussion of design options for heat pump and instantaneous water heaters.

Heat Leaks

Fittings such as inlet and outlet water pipes, drain valve, legs, and thermostat "leak" heat to the surrounding air via convection and radiation. This heat energy loss results from conduction from the stored water through the jacket insulation to the outer exposed surface. Fittings act like "fins" in their heat loss characteristics to the surrounding air. Heat transfer from the "fin" to the air depends upon the "fin" size and material. However, the size of a given fitting is not as important as the thermal contact it makes with the tank cover. Fittings that touch the cover, conduct more heat out than those that don't touch. Heat is also lost to the floor through the legs if they are attached to the main combustion chamber.

Heat "leaks" can be minimized by combining fittings (two or more fittings attached at one location), building them out of plastic, or isolating them from the outer tank cover. Computer simulations[7] show an annual energy savings of about 2% if a conventional water heater with five fitting "leaks" is constructed without "leaks". Isolating the legs from the combustion chamber saves an additional 1%.

The design options discussed in this section can be separated into two categories: those that reduce standby flue losses and those that increase recovery efficiency. The first three options (reduced pilot light, automatic ignition with damper, and indirect heating) belong in the first category, and the last five (increased flue baffling, multiple flues, submerged combustion chambers, pulsed combustion, and condensation of flue gases) in the second category.

Reduced Pilot Light Input Rate

A reduced pilot light input rate can be obtained by replacing the pilot jet with one that has a smaller orifice size. Pilot light flame can be reduced to the point just before the flame is extinguished by drafts or fluctuations in the natural gas supply pressure. Energy savings from reduced pilot light gas consumption are partially offset by decreased heat gain from the pilot light; that is, part of the pilot light heat input serves to compensate for standby losses through the jacket. Therefore, the stored water cools off more quickly with a lowered pilot light than with a higher pilot light heat rate. Nevertheless, a reduced pilot light heat rate saves energy. One study found that a reduction in pilot light heat rate from 700 to 330 Btu/h results in a 2% reduction in energy use[7]. Another study predicts an 8% reduction in energy use for a decrease in heat rate from 750 to 380 Btu/h[10]. Pilot light input rate for efficient gas water heaters is in the range of 350 to 450 Btu/h.

Automatic Ignition With a Flue Damper

Elimination of a continuous pilot light, substitution of an an electronic ignition and use of a flue damper are effective measures, when combined, to reduce standby losses in a gas water heater. The flue damper reduces standby losses significantly when the main burner is not on. However, there must be a device to check that the damper is not closed when the burner is on. Since prototype gas water heaters and some commercial water heaters have used intermittent ignition devices, the technology is presently available.

Elimination of central flue and indirect heating of water

In conventional water heaters, the central flue acts as a heat exchanger between the hot combustion gases and the water. Approximately 15% of the energy input is lost up an open flue during standby periods. Indirect heating (like electronic ignition and a flue damper) will reduce much of this standby loss. Indirect heating can be accomplished in several ways. In the first method, a heat transfer fluid is pumped through the hot combustion gases, where it picks up heat energy; the fluid then transfers most of this energy to the water in the storage tank. There is a reduction in standby losses from the storage tank since heat does not escape from the tank through convection up a central flue. The standby loss from the storage tank is not completely eliminated as some heat is lost through the connecting pipes. In the second method, heat is transferred from the combustion gases to the water via a heat pipe. The heat transfer fluid that circulates within the heat pipe could be water or some other fluid. The fluid vaporizes as it is brought near the flame and condenses as it moves away from the flame; it then loses heat to the water. There have been corrosion problems in heat pipes incorporated in some commercially available residential water heaters.

Increased flue baffling with forced draft

The recovery efficiency of gas water heaters can be increased by restricting the total air flow with increased baffling of the combustion gases as they pass through the central flue. Standby losses also decrease because of the lower natural draft losses in the flue during off periods. Increased baffling can be achieved by adding interference tabs or by manufacturing the flue baffle as a series of reversing spirals. This allows more heat energy to be transferred from the flue gases to the water before the gases exit the central flue. Since the flue gas temperature decreases as more heat is transferred to the water, the pressure drop in the flue increases, eventually requiring a forced draft. The use of a forced draft allows further reductions in flue temperature and in excess air, thus increasing the heat energy transferred from the combustion products to the water. Forced draft is not presently used in commercially available residential water heaters. The forced draft can be accomplished by using an exhaust fan at the top of the vent (induced draft) or by a blower (power burner) at the burner.

Multiple flues

Another method of possibly increasing the recovery efficiency of gas-fired water heaters is to increase heat transfer with multiple flues. Such a flue system is presently found in one commercially available, high-efficiency residential water heater model. Multiple flues have more surface area than a single flue of the same height, and, therefore, transfer more heat energy to the surrounding water than a single flue. This increase in heat transfer usually outweighs the possible increase in standby losses. Condensation of water vapor is possible at a high recovery efficiency. Therefore, collection of condensate may be necessary unless corrosion resistant materials that are more expensive than those now in use are used to construct the flue.

Submerged combustion chamber

Submerged combustion chambers are also presently used in commercially available residential water heaters. In such water heaters, the combustion chamber is completely surrounded by water. Heat cannot escape through the sides or bottom of the burner compartment without heating the water. In some chambers, a baffle restricts air flow in the off cycle, thereby reducing standby losses, so the recovery efficiency is increased and the standby losses are decreased. Recovery efficiencies of about 85% have been achieved with submerged combustion chambers in gas-fired water heaters[11].

Pulsed Combustion

Pulsed combustion has been used for several years in gas furnaces and boilers. In a pulsed combustion chamber, an electric spark is used to ignite a natural gas/air mixture. The mixture is delivered to the combustion chamber through a valve that is forced closed by ignition. The ejection of a pulse of hot gases through the exhaust pipe creates a temporary partial vacuum, the valve is re-opened, and additional fuel mixture is drawn into the chamber. Enough heat energy remains to ignite this incoming fuel/air mixture. There is an efficient transfer of heat energy to the water as shock waves travel through the flue. There is, however, some concern about the noise level produced in a pulsed combustion system. Because of the explosive process, such systems need good sound control. These designs can have a recovery efficiency near 90% and loss up the flue can be essentially eliminated[12].

Condensation of Flue Gases

When a hydrocarbon such as natural gas is burned, one of the combustion products is water vapor. If the water vapor can be condensed, its heat of vaporization will be available to further increase the water temperature. It is estimated that approximately 8% of the input fuel energy could be recaptured by condensation of all the water vapor in the combustion products[13]. For oil-fired combustion, the latent energy is less, equalling approximately 6.5% of the input fuel energy. The exiting flue gas temperature must be much lower than in a typical water heater. A

temperature between 100 and 120°F is low enough for condensation to occur. Improved heat transfer from flue gases to water is necessary to reach such low exiting flue gas temperatures. Pulsed combustion is one method of improving the heat transfer sufficiently to achieve flue gas temperatures below 120°F. A drain must be provided for removal of the condensed water vapor. Lower flue gas temperature may allow for venting of combustion gases through a horizontal plastic pipe, thus reducing the initial cost of the water heater plus vent system.

Oil-fired water heaters

Except for elimination of the gas pilot light option, the design options described immediately above for gas-fired water heaters can be applied to oil-fired water heaters. A few differences are discussed below. Oil-fired water heaters are constructed with either central or external flues. The flue damper design option will have a greater effect on reducing standby losses in the external flue design. Since a fan is used to provide combustion air, there is less natural draft in the central flue design than in the external flue design. Design options (4), (5), and (6) (elimination of central flue, increased flue baffling with forced draft, and multiple flues) can all be carried out for oil-fired water heaters. A submerged combustion chamber is possible for oil-fired water heaters but there is the problem of increased soot if the flame temperature is too low. An additional design option for oil-fired water heaters is the reduction of energy use by the ignition transformer. This transformer need only operate until ignition is achieved (about 15 seconds) rather than during the full burner time (about 1.0-1.5 hours per day). The potential energy savings are small, only about 200 Wh per day.

Heat pump water heaters

Design options for improving the energy efficiency of heat pump water heaters can be separated into two categories: those common to gas-fired, oil-fired, and electric resistance storage type water heaters (described earlier) and options that improve the efficiency of heat pumps. The former include increased jacket insulation (for heat pump water heaters with a tank), use of anti-convection valves, and reduction of heat "leaks". The latter include:

For Heat Pump Water Heaters with Tanks:

1) Increased heat exchanger effectiveness for evaporator and condenser,
2) Improved compressor efficiency,
3) Improved fan and fan motor efficiencies, and
4) Improved compressor motor efficiency;

For Heat Pump Water Heaters without Tanks:

1) Increased heat exchanger effectiveness for evaporator and condenser,
2) Improved compressor efficiency,
3) Improved fan and fan motor efficiency,
4) Improved compressor motor efficiency,
5) Improved water circulating pump and pump motor efficiencies,
6) Improved heat exchanger insulation, and
7) Improved connecting hose insulation.

Some of these design options are described in detail under "Energy Conservation Measures for Central Air Conditioners Including Heat Pumps".

Instantaneous water heaters

A design option that would reduce energy use for both gas and electric instantaneous water heaters would reduce the amount of leftover water in the heater after each draw. Heat energy is lost as this small volume of hot water falls in temperature. Gas-fired instantaneous water heaters can be more efficient if they employ a reduced pilot light input rate (by use of automatic ignition with a flue damper), increased flue baffling with forced draft, and use of multiple flues. Advanced design options, such as pulsed combustion and condensation, are also potential conservation measures for gas -fired instantaneous water heaters. These design options were all described earlier for gas-fired storage type water heaters.

REFERENCES

1. Personal communication with Don Farrell, Fuel Oil and Oil Heat Magazine Fairfield, NJ.

2. "A Limited Investigation of the Energy and Demand Management Potential for the Temcor/Energy Utilization Systems Heat Pump Water Heater", Pennsylvania Power and Light Company, August, 1981.

3. A. Usibelli, "Monitored Energy Use of Residential Water Heaters," (1984), Proceedings of ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Volume E, ACEEE, 1001 Connecticut Avenue, N.W., Washington, D.C. 20036.

4. Directory of Certified Water Heater Efficiency Ratings, Gas Appliance Manufacturers Association, Arlington, VA 22209, January, 1986.

5. "Water Heater Insulation WH-400", Owens-Corning Fiberglass Corp., Toledo, OH 43659.

6. "ASHRAE Handbook 1985 Fundamentals", ASHRAE, Atlanta, GA 30329.

7. "Study Of Energy-Saving Options For Refrigerators and Water Heaters, Volume 2: Water Heaters," (1977), Arthur D. Little, Inc. Cambridge, MA 02140.

8. C. W. Ek and C.D. Auburg, "Electric Water Heater Standby Losses: Comparison of Conservation Strategies and Their Energy Savings," (1984), Proceedings of ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Volume E, ACEEE, 1001 Connecticut Avenue, N.W., Washington, D.C. 20036.

9. "Energy Conservation Program for Consumer Products" 10 CFR Part 430, Chapter II, Revised 1-1-85.

10. R.A. Hoskins an E. Hirst, "Energy and Cost Analysis of Residential Water Heaters", ORNL/CON-10, Oak Ridge National Laboratory, Oak Ridge, TN, June, 1977.

11. Brochure for Nautilus water heater, manufactured by Mor-FLo American, 2341 Michigan Avenue, Santa Monica, CA 90404, Sept., 1984.

12 W. Thrasher, R. Kolodgy, and J. Fuller, "Development of a Space Heater and a Residential Water Heater Based on the Pulsed Combustion Principle", Proceedings of the ACEEE 1984 Summer Study on Energy Efficiency in Buildings, Volume E, ACEEE, 1001 Connecticut Avenue, N.W., Washington D.C. 20036.

13. S. Lewis, "High Efficiency Heaters", Solar Age, March, 1986.

ENERGY CONSERVATION MEASURES FOR ROOM AIR CONDITIONERS

INTRODUCTION

A room air conditioner is an enclosed unit that mounts in a window or through the wall and provides conditioned air to an enclosed space. It includes a prime source of refrigeration and may include a means for ventilating and heating.

PRODUCT CLASSES

Original Classes

Six classes (see Table 8) of room air conditioners (RAC) were specified in the original analysis. They are distinguished by (1) capacity, (2) configuration, or (3) design of the unit.

TABLE 8. PRODUCT CLASSES FOR ROOM AIR CONDITIONERS

1) With Outdoor Side Louvers; 8,000 Btu/h and under
2) With Outdoor Side Louvers; greater than 8,000 Btu/h through 14,000 Btu/h
3) With Outdoor Side Louvers; greater than 14,000 Btu/h through 20,000 Btu/h
4) With Outdoor Side Louvers; greater than 20,000 Btu/h
5) Without Outdoor Side Louvers, and Reverse Cycle; 8,000 Btu/h and under
6) Without Outdoor Side Louvers, and Reverse Cycle; greater than 8,000 Btu/h

The unit voltage will also affect the room air conditioner utility; however, engineering analyses indicated that there is no difference in efficiency between units designed to operate at difference voltages, and, therefore, no separate product classes were needed to reflect voltage. Since engineering considerations dictated that units rated above approximately 20,000 Btu/h, which can be fitted into standard windows, cannot achieve as high an efficiency as smaller units, a product class for units above 20,000 Btu/h was established. A product class was also established for units below 8,000 Btu/h. They show somewhat reduced performance as a result of their compact design, which increases air system losses.

Room air conditioners without outdoor side louvers provide utility because they can be mounted flush with the outside wall. These units were segregated from those with outdoor side louvers since the louvers result in inherently higher efficiency. This higher efficiency results from a reduced air flow pressure drop offered by the side louvers.

The reverse cycle room air conditioner offers the utility of heating as well as cooling. However, its design results in an efficiency that is potentially lower than that of the cooling-only units. The reversing valve, which allows the unit to be switched from cooling to heating, represents an additional source of inefficiency. Units without side louvers and units with reversing valves were grouped together in one class, since they are less efficient than other types.

New Classes

It appears that even with the changes in design over the last six years, the current six product classes are still appropriate.

DESIGN OPTIONS

Options from Previous Analysis

Design options employed in the original analysis of room air conditioners consisted of:

1) Increased heat-transfer surface area (sometimes accompanied by decreased compressor size), and
2) fan motor improvement or replacement.

The heat exchanger surface area was generally increased by using a coil with a larger frontal area. In some cases, an increase in the heat exchanger depth increased the efficiency slightly; however, this improvement was partially offset by increased air system losses. As the heat-transfer surface increases, the compressor displacement must be reduced to maintain the desired unit capacity.

The effect on cost of reduced compressor displacement was assumed to be reflected through reduced piston stroke. In addition to changing pump displacement, the manufacturer would change the compressor motor as well. Often, the reduced capacity compressor for the highest efficiency design was already available as the next logical increment that the compressor manufacturer offered.

The heat-transfer surface areas were increased within a given cabinet size up to a limit dictated by the cabinet frontal area, reduced by a factor to allow for end turns and return air for the evaporator. Within a given cabinet, an increase in evaporator frontal area was accommodated through a decrease in the size of the return air flow passage, which results in increased pressure drop and required air power. Optimization of the evaporator size versus the return duct air pressure drop was not performed as no data were available on the amount of pressure drop in a highly constricted duct.

It was assumed that the utility and performance of a room air conditioner required the suction temperature to remain below 55 °F, so heat exchanger surface areas and evaporator air flow

volumes were adjusted to keep the suction temperature below that level. This upper limit on the suction temperature represents a substantial limitation on the achievable unit efficiency with available compressors. A standard 10 °F of condenser liquid subcooling as well as a 10 °F evaporator superheat was assumed throughout the analysis.

Additional Design Options

Table 9 lists additional design options under consideration for inclusion in the forthcoming engineering analysis. The most significant potential improvements for the RAC will be in compressor design. American and Japanese compressor manufacturers have introduced and will introduce rotary and scroll compressors, which offer quieter and more efficient operation in a smaller package. The advanced rotary or scroll type compressor (single speed) could offer a 20% improvement in compressor efficiency over units currently available. The benefits of these designs are generally lower valve and mechanical friction losses, with comparable leakage rates (the weak point of earlier rotary compressors).

TABLE 9. ADDITIONAL DESIGN OPTIONS FOR ROOM AIR CONDITIONERS

1) Improved compressor efficiency
2) Variable speed compressors
3) Mixed refrigerants
4) Electronic expansion valves
5) Thermostatic cyclic controls
6) Improved fan and fan motor efficiency

The valveless low inertia feature of the rotary or scroll compressor lends itself to higher speed operation than 60 Hz synchronous motors, which could be achieved with new, solid-state electric motor speed controllers. The variable speed motor controller, combined with the rotary or scroll, can provide cooling capacities equivalent to those of traditional room air conditioners, the variable speed models use much smaller hardware and can also operate at lower, more efficient speeds when the cooling requirement is reduced. The variable speed compressor can thus be used to produce variable cooling capacity. The savings would be dependent upon the test procedure adopted for RACs with variable capacity. It is difficult to estimate the energy savings of RACs with variable capacity; they are probably about 10%.

Mixed refrigerants (non-azeotropic) can improve efficiency by providing more ideal heat exchanger characteristics. It is estimated that as much as a 10% improvement in efficiency could be achieved with mixed refrigerants. Mixed refrigerants, however, require a heat exchanger design with an increased number of tube passes and deeper, smaller, frontal area to achieve the

necessary counterflow heat exchange.

Some attention has been given to control improvements for the RAC, including both electronic expansion valves and remote thermostatic cyclic controls, which more accurately monitor room air temperature than the current built-in thermostats. While the remote thermostat may offer comfort improvements, efficiency gains would require that it be coupled with improved air flow discharge/distribution so as to better mix the room air. This would go hand in hand with larger (more efficient) heat exchangers and more efficient air flow handling. The electronic expansion valve (and interchanger heat exchanger) has not, to our knowledge, demonstrated efficiency improvements. However, there are, theoretically, gains to be made with these components. In a room air conditioner, fans are used to move air past both heat exchangers. Improvements in both fan motor and fan mechanical efficiency can increase the overall efficiency of a room air conditioner.

o

HOME HEATING EQUIPMENT NOT INCLUDING FURNACES

INTRODUCTION

Home heating equipment, not including furnaces, includes both vented and unvented products that furnish heat to a space proximate to the heater, and directly from the heater, without duct connections. Vented home heating equipment is denoted as such because combustion products are exhausted to the outdoors through a closed venting system; it includes vented wall furnaces, floor furnaces, and room heaters. Unvented home heating equipment is denoted as such because combustion products are not exhausted to the outdoors. It includes electric heaters and unvented gas and oil heaters.

PRODUCT CLASSES

Original Classes

Eight classes of vented home heating equipment were originally established by DOE (see Table 10). Six of these classes are gas-fired and two are oil-fired . Unvented home heating equipment can be considered almost 100% efficient since essentially all the fuel energy (excluding latent heat) is transformed to heat energy and is delivered to the space in which the heater is located. Therefore, design options to improve the efficiency of unvented heaters are not discussed. Product classes are disaggregated by location of the heater (floor, wall, free-standing), gravity or forced air delivery, and direct or standard venting, as well as fuel type. Room heaters with forced air delivery require electricity whereas gravity type heaters do not. Direct venting means that outside combustion air is brought to the heater and that combustion gases are exhausted through a vent pipe to the outdoors. Standard venting means that combustion air comes from the ambient air in the vicinity of the heater and that combustion gases are exhausted through a pipe to the outdoors.

TABLE 10. PRODUCT CLASSES FOR HOME HEATING EQUIPMENT

1) Gas Gravity Direct - Wall Unit
2) Gas Gravity Standard - Wall Unit
3) Gas Forced Air Direct - Wall Unit
4) Gas Forced Air Standard - Wall Unit

5) Gas Room Heater

6) Gas Floor Furnace

7) Oil Wall Unit/Floor Furnace

8) Oil Room Heater

Vented wall furnace means a self-contained vented heater complete with grills or the equivalent, designed for incorporation in, or permanent attachment to, a wall of a residence. Furnishes heated air through openings in the casing and circulates the air by gravity or by a fan directly into the space to be heated. Direct and standard venting are both available for wall furnaces. A vented floor furnace is a self-contained vented heater suspended from the floor of the space being heated, taking air for combustion from outside this space. Gas and oil-fired floor heaters form separate classes. The vented floor furnace supplies heated air through openings in the casing and circulates the air by gravity or by a fan directly into the space to be heated. A vented room heater is a self-contained, free-standing, nonrecessed, vented heater for furnishing warmed air to the space in which it is installed. The vented room heater supplies heated air through openings in the casing and circulates the air by gravity or by a fan directly into the space to be heated. There are two classes of vented room heaters; oil-fired and gas-fired.

New Classes

At the present time, no new classes of home heating equipment have been identified.

DESIGN OPTIONS

Options From Previous Analysis

Five design options were considered in the previous analysis. These are listed in Table 11.

TABLE 11. DESIGN OPTIONS FOR HOME HEATING EQUIPMENT

1) Increased Heat Exchanger Surface Area

2) Intermittent Ignition Device

3) Vent Damper (Electrical and Thermal)

4) Improved Blower Motor Efficiency

5) Power Burner or Power Vent

The steady-state efficiency of home heating equipment can be improved by increasing the heat exchanger surface area or by increasing the effectiveness of the heat exchanger. The latter is accomplished by increasing the heat transfer rate from the products of combustion to the heating medium (air).

Intermittent ignition devices can be used in gas-fired home heating equipment instead of pilot lights. The intermittent ignition device, which requires electrical power, eliminates pilot losses, which are estimated (for gas furnaces) to be 2.4% annually if the pilot is off during the summer and up to 4.0% if the pilot is on during the summer. Since the AFUE (Annual Fuel Utilization Efficiency) calculations assume summertime usage of the pilot, and since pilot light rates of vented heaters are usually a greater percentage of the total input than is the case for gas furnaces, the pilot light losses for vented home heaters will typically be in excess of 4%.

Off-cycle convective heat losses can be significantly reduced with the use of a vent damper. A damper can be used with gas or oil-fired home heating equipment. An electrically powered vent damper automatically closes when fuel to the main burner is shut off by the thermostat control. An electric motor or solenoid is used to position the damper. A safety switch is necessary to prevent the gas valve from opening until the damper has opened. It is possible to use a thermally activated vent damper that opens when hot flue gases impinge upon it. An electrical connection would not be needed for its operation, although a safety switch should be provided that prevents the gas valve from opening until the damper has opened.

Several classes of home heating equipment employ a circulating air fan, or a blower, which moves warm air from the heater into the room. A small overall efficiency improvement can be accomplished by using more efficient fans and fan motors. However, if AFUE is used as an efficiency descriptor, fan energy use is not taken into account in calculating heating efficiency.

A forced draft or induced draft fan for power venting eliminates reliance on the natural chimney draft for venting. The advantages of providing power venting include a greater degree of control of combustion air, which limits excess air, and restriction of air flow through the flue during off-cycle conditions, which reduces off-cycle heat exchanger losses. The fan can be installed so as to pressurize the combustion chamber (forced draft) or to produce a negative draft (induced draft).

Additional Options

Two design options which were not considered in the previous analysis are pulsed combustion and condensing heaters, and modulating burners. Gas-fired warm air furnaces already extensively use condensation of water vapor to improve steady-state efficiency. There is no inherent reason why this technology could not be employed in home heating equipment. However,

a means of disposing of condensed water vapor would have to be provided.

If the "on" time of the heating system could be increased, the seasonal efficiency of home heating equipment could be improved. Reducing the fuel input rate to the burner in response to lower room heating requirements could increase "on" time. For maximum benefit, systems which modulate fuel input should also modulate combustion air, keeping the fuel to air ratio constant. Fuel and air input can be modulated in steps, or continuously. A regulating valve would be used to control the firing rate of the burner according to signals received from a thermostatic control device. Air modulation can be accomplished by using a variable position damper in the flue passage draft hood or for gas-fired systems, by using a variable position damper in the secondary combustion air inlet.

Because of a 1984 amendment to the test procedure for vented heaters, modulating controls are now addressed. Currently, provisions for testing condensing vented heaters are not included, but could be by adopting the provisions for condensing furnaces.

No design options have been identified for unvented home heating equipment.

ENERGY CONSERVATION MEASURES FOR TELEVISIONS

INTRODUCTION

Televisions receive transmitted modulated radio-frequency signals which they demodulate to produce visual images and sound. The display device for most televisions is a cathode ray tube, which is an evacuated tube containing an electron gun, and a phosphor screen that emits light when excited by the electron beam. A filament is heated and supplies electrons that are accelerated by an electric field. Energy is expended to amplify the signal, heat the filament, accelerate the electrons, and to control the position of the beam on the screen. Special features, such as instant on and remote control, also consume some energy. The energy efficiency of a television is characterized as a receiver energy efficiency factor (REEF) which is equal to the product of the estimated minimum average power consumption (0.130 kW) and 2,200 hours/yr divided by the measured average annual energy consumption in kWh/yr. The result is multiplied by 100 and expressed as a percent.

Color receivers are more complex than monochrome because they must handle additional information to produce color. Many color televisions use a shadow-mask color kinescope, in which color images are produced in the form of closely intermingled red, blue, and green dots. The primary color phosphor dots are excited by three separate electron beams, which are prevented from striking dots of the wrong color by the shadowing effect of the mask.

PRODUCT CLASSES

Original Classes

In the previous analysis, two classes of televisions, color and monochrome, were designated. They differ in utility and in energy use, with color sets using more energy than monochrome.

New Classes

New classes of televisions have not been identified.

DESIGN OPTIONS

Testing has shown that television sets of the same size exhibit a wide range of annual energy use. Sets with a 19" diagonal screen size and options 2,3,5, and 6 listed below show a factor of two difference in annual energy consumption[1]. Sets with a 25" diagonal screen size and the same

options show a variation of more than 50% in annual energy consumption. Testing of 19" color sets reported on in Consumer Reports showed almost a factor of two variation (60 -115W input) in power input[2].

Options From Previous Analysis

All televisions now sold have solid-state components and no longer have instant-on features. Some of the factors (aside from screen size) influencing energy usage are shown below:

1) remote control,
2) electronic tuning,
3) automatic color control,
4) vertical interval reference,
5) brightness sensor, and
6) voltage regulating power source.

Not much information appears to be available on the energy consumed by these special features, except for remote control. A report by Value Engineering Lab estimates 3-5 Watts input for remote control in television sets that they examined[3]. Additional test data are needed to ascertain the energy use impact of all the features listed above.

The last design feature (voltage regulating power source) could use a large amount of energy input to the television set. Very simple regulators, such as zener diode parallel shunts, simply "dump" the output of the power supply to ground when the load demand is low. In recent years, many power supplies have been designed that use integrated circuit voltage regulators, which are essentially active series regulators. Properly applied, these devices will provide regulation with a small internal power dissipation compared to the load.

Additional Options

There are two television set design options that were not considered in the previous analysis. One is replacement of the cathode ray picture tube by a less energy intensive display device. Three types of low-power flat screens being developed are liquid crystal displays, gas plasma displays, and electroluminescent displays. The second design option is replacement of a color television's three electron guns by one gun. Estimates of energy savings to be derived from these design options are unavailable.

REFERENCES

1. "Energy Consumption Testing of Television Sets," Science Applications Inc., La Jolla CA, November, 1980.

2. "19 Inch Color TV's", Consumer Reports, January, 1981.

3. Energy Efficiency Program For Appliances-Television Sets, Value Engineering Laboratory, Alexandria VA 22303, October, 1977.

ENERGY CONSERVATION MEASURES FOR HOUSEHOLD RANGES AND OVENS

INTRODUCTION

This category includes consumer products that are used as major household cooking appliances. They use gas or electricity to cook or heat different types of food. Electricity may be used for resistance or microwave heating. The product type includes horizontal cooking surfaces and either conventional or microwave ovens, or combinations of these product classes.

PRODUCT CLASSES

Original Classes

Nine classes of kitchen ranges and ovens were originally specified by DOE. These are shown in Table 12. These product classes are distinguished by: (1) the kind of energy used for cooking, (2) their specific function, (3) the types of oven cleaning system and (4) utility features.

TABLE 12. PRODUCT CLASSES FOR RANGES AND OVENS

1) Electric Oven
2) Electric Oven, Self-Cleaning
3) Electric Cooking Top
4) Gas Oven, Standard, without Electric Power Cord
5) Gas Oven, Standard, with Electric Power Cord
6) Gas Oven, Self-Cleaning
7) Gas Cooking Top without Electric Power Cord
8) Gas Cooking Top with Electric Power Cord
9) Microwave Oven

Product classifications are established for appliances that use a different energy source. These energy sources are gas and electricity. Three product classes are based on the function of the appliance. Ovens have an intended function different from that of cooking tops. The different method used in transferring heat to the food results in the cooking top being inherently more efficient, so ovens and cooking tops are in different product classes. A separate product class is provided for microwave ovens because these ovens use a cooking process different from that of conventional electric ovens.

Type of oven cleaning system is a performance-related feature that affects utility. The three types of oven cleaning systems are the standard, the continuous cleaning, and the self-cleaning system. The standard, or non-cleaning, oven is cleaned by the consumer and uses no electricity or gas for cleaning. The continuous cleaning system is a catalytic process where, during normal operation, soil is soaked up on to the oven surface which is coated with an oxidizing catalyst. The self-cleaning system is a pyrolytic process where soil is oxidized during a special self-cleaning cycle. Self-cleaning ovens have added insulation because they operate at higher temperatures during the cleaning cycle than during cooking. The continuous cleaning oven tends to be as energy efficient as the standard oven. Even though the continuous cleaning oven has greater utility than the standard oven, one product class is established for both continuous cleaning and standard ovens because they tend to use the same amounts of energy. Many consumers prefer the self-cleaning oven. As the self-cleaning oven uses electricity or gas during the cleaning cycle and is better insulated, its energy consumption is different from the standard and continuous cleaning ovens. Since the self-cleaning oven provides a new utility to the consumer, it is in a separate product class.

Ranges and ovens with pilot lights are less energy-efficient than identical products with electronic ignition. DOE recognized the utility of pilot lights in situations where an electric outlet is not located near the range. As a result, gas ranges and ovens were partitioned into classes with and without electric power supplied.

Large ovens are less energy-efficient than small ovens because of their increased surface area, which adds to thermal losses. Large ovens offer the utility of being able to handle larger food dishes. Volume-efficiency relations have been developed to accommodate this effect so that a separate product class based on oven size is not required.

For cooking tops and conventional ovens there is a relationship between efficiency and size. This relationship applies both to the burners on the cooking top and to the ovens. For the cooking top, the efficiency relationship depends on the match between the size of the test load and the size of the burner.

For conventional ovens, the variation between energy factor and efficiency results from larger ovens having greater thermal mass and higher vent rates than smaller ones. Since the standard test is a transient test with a fixed test load, the increased energy consumption due to increased mass with larger units yields a lower energy factor. There is an approximately linear relationship between oven volume and energy factor, with negative slope.

New Classes

Since the original analysis, a number of new products have come on the market. In most cases, these may be considered design options that could replace conventional burners or heating elements on gas or electric ranges. Examples include:

1) Solid Element: this is a type of electric hob commonly used in European cooktops. It has a greater thermal mass than elements commonly found in U.S. ranges, and runs at a lower surface temperature. Solid element hobs maintain flatness better over time than U.S. elements and thus couple better to pans.

2) Halogen: halogen lights are used in ceramic cooktops to heat pans with infrared energy.

3) Radiant Gas Burners: a new type of burner to reduce NO_x production is currently under development. Natural gas is burned in a chamber placed below a ceramic plate. The plate becomes a radiator of infrared energy and a gas jet passes through holes in the plate, imparting additional energy to the cooking utensil. This type of burner could provide consumer utility with a higher efficiency than conventional burners.

4) Induction: induction cooktops are currently being marketed in the U.S., Japan and Europe. These heat by inducing eddy currents directly in the pan so that the cooking surface remains cool. Although the heating of the food by the pan is efficient, the overall efficiency of the system may not be as high as that of conventional units.

5) Convection Ovens: convection ovens are not currently treated as a separate product class. They were considered in the previous analysis, but it was determined that a separate class was not justified because they offered no clear enhanced consumer utility or reduced energy use.

At this time, additional data are needed to decide whether there is an inherent difference in these units related to efficiency and utility before we can decide whether new product classes are required.

DESIGN OPTIONS

Options from Previous Analysis

The design options used in the original analysis (Table 13) are still valid.

TABLE 13. DESIGN OPTION SUMMARY

1) *Improved Insulation*

Denser fiberglass insulation is used to reduce losses. Increased insulation thickness was not considered a viable option as it requires a reduction in cavity size and a corresponding reduction in consumer utility.

2) *Reduced Vent Size*

Vent rate in standard ovens is reduced to the rate of self-cleaning ovens by either reducing the vent tube size or adding a baffle.

3) *Reduced Conduction Losses*

Standard oven suspension has been upgraded to the level of self-cleaning ovens. This includes modifications at the door: adding another thermal break, an improved gasket, and a modified inner panel.

4) *Improved Contact Conductance*

This applies to sheath-type electrical resistance cooking tops. Their efficiency is improved by designing them to maintain better thermal contact with cooking utensils.

Additional Options

A few additional design improvements are possible. A reduction of thermal mass in the stove top and oven could reduce energy use. Insulations with lower conductivities may be introduced in the next 10 years; however, at this time, none have been identified. One possibility is to use evacuated panel insulation, as discussed for refrigerator/freezers. However, there are potential problems associated with outgassing of plastics subjected to high temperatures and subsequent degradation of the vacuum.

Some of the burner designs discussed above, such as radiant burners, may offer improved efficiency with enhanced user utility. Additional data are needed on these designs. The use of reflective surfaces could also enhance oven performance. For example, reflective ovens and broilers may use less energy. However, the current DOE test procedure does not measure broiler energy use.

ENERGY CONSERVATION MEASURES FOR CLOTHES WASHERS

INTRODUCTION

A clothes washer is a consumer product designed to clean clothes by using a solution of soap and/or detergent, and water and mechanical agitation or other movement. Clothes washers use electricity to run a drain pump and motor. They also require hot water, which is supplied by a separate water heater. Most of the energy used by clothes washers is for water heating. Their efficiencies are expressed in number of loads times volume per kWh of total energy used. The clothes are washed, rinsed, and spun dry inside an insulated cabinet. Top loaders circulate clothes up and down and back and forth (motion is about a vertical axis) while front-loaders tumble clothes up and around (motion is about a horizontal axis). A water level control allows the user to adjust the amount of water used to the size of the wash load, thereby saving water, detergent and energy. Water is automatically fed to the machine through electrically operated valves, one connected to the hot water pipe, and the second to the cold water pipe.

A typical top-loading clothes washer has an opening, covered by a door, which gives access to the inner basket where the load to be washed is placed. The inner basket is either perforated or solid and is surrounded by a larger outer tub which holds the water when the machine is running. The inner basket contains an agitator, which undergoes a reversing circular motion, provided by an electric motor through a transmission and linkage. The spinning action of the inner basket and the drain pump are also powered by the motor.

The typical clothes washer cycle proceeds as follows: the basket is filled with water which suspends the load being washed to a selected level. The motion of the agitator causes a turbulent environment, which provides friction between the load, basket, and agitator. After the wash and rinse periods, the water is drained and the basket begins to spin, creating centrifugal forces, which remove more water from the load.

PRODUCT CLASSES

Original Classes

Three classes (see Table 14) of clothes washers were identified in the previous analysis: top loading, front loading and washers with suds-saving features. Front loaders use less water than top loaders and thus less energy. Top loaders spin the clothes drier. Suds savers can reuse suds and warm water from an earlier wash by pumping them back into the washer.

New Classes

It has been suggested that top loading automatic washers be divided into three classes by capacity: compact (1.6 ft^3 or less), standard capacity (1.61 to 2.59 ft^3), and large capacity (2.6 ft^3 or greater). Classes 4 through 7, if selected, would replace the first class. It has also been recommended that a separate class be designated for semi-automatic clothes washers. DOE has estimated higher hot and warm water usage for semi-automatic than for fully automatic clothes washers.

TABLE 14. PRODUCT CLASSES FOR CLOTHES WASHERS

1) Top Loading
2) Front Loading
3) Suds Savers
4) *Top Loading, Compact**
5) *Top Loading, Standard**
6) *Top Loading, Large**
7) *Top Loading, Semi Automatic**

DESIGN OPTIONS

Most of the energy used by washing machines is for heating water. Except for reducing the electrical input energy to the electric motor (which provides mechanical energy to agitate and spin the clothes), not much can be done to reduce energy use other than reducing the amount of energy used for water heating. Water heating energy can be reduced by decreasing the amount of water utilized or the temperature of the water needed for washing. Presently, in the U.S., top loaders are much more popular than front loaders, which use less water.

Options From Previous Analysis

The following design options from the previous analysis are discussed below:

1) Eliminate warm rinse
2) Improve fill control
3) Change configuration to reduce water use
4) Reduce thermal mass

*Items in italics are new classifications under consideration.

5) Save suds

6) Add insulation

7) Increase motor efficiency

8) Add thermostatically controlled mixing valves

Eliminating the warm rinse option will reduce hot water consumption. It is generally agreed that the elimination of this option will not adversely affect the performance of clothes washers. Washers either have an option of use of warm or cold water for the rinse or allow only a cold rinse.

Most washers have an optional fill volume control which allows the user a choice of water volumes for varying levels of loads. The amount of water needed to wash a load of clothes depends upon the amount and type of clothes and on the kind of dirt on the clothes. If an automatic control device could adjust the water level according to these three factors, hot water used would be minimized. At the present time, the choice of water volume is up to the user.

Any change in geometry that could reduce water usage will reduce hot water energy consumption. An example of such a change would be a reduction in the space in between the clothes tub and the outer tub. This would reduce the volume of water contained between the two tubs.

Some of the heat energy contained in the hot water entering the clothes washer is used to increase the temperature of the tank. The heat energy transferred to the tub depends on the mass of the tub and the specific heat of the material composing the tub. Reducing the mass of the tub and choosing a material of lower specific heat than now used will reduce the transfer of heat energy from the hot water to the tub. Only small improvements in efficiency are expected from this measure since the mass cannot be reduced very much and most of the thermal energy is contained in the hot water. Additionally, the substitution of a lighter tub constructed of aluminum (instead of steel and porcelain) is partially offset by the higher specific heat of aluminum.

The next design operation (suds saver) is useful only when more than one load of wash is done per day. Some clothes washers are designed to reuse wash water by pumping it into a storage tub rather than down the drain. The sudsy water remains in the tub, allowing soil to settle to the bottom. After settling, the water may be pumped back into the washer for the next wash load. The water will have cooled down somewhat, but will still be warmer than the usual inlet temperature to the water heater. Therefore, less energy will be used to reach the operating wash temperature than is usually required. Energy, detergent, and water use are reduced if the suds saver feature is used.

Some heat energy is lost through the shell of the clothes washer. If this heat loss were reduced, the efficiency of the washer would increase. Adding insulation will improve the efficiency

slightly by allowing only a small loss of heat from the inlet water to the ambient air. The wash cycle is relatively short (about 20 minutes), so there is only a short period in which heat is lost to the ambient air; therefore, added insulation will cause only a small improvement in efficiency.

The electric motor uses about 5% of the total energy consumed by a clothes washer. Therefore, a 20% improvement in motor efficiency would yield only a 1% improvement in total efficiency. A capacitor-type motor is more efficient than a split-phase motor because of its improved power factor; reduced heating losses in the stator portion of the capacitor-type motor means electrical input energy is used more efficiently than in a split phase motor.

The warm water needed for washing and sometimes for rinsing is produced by mixing a fixed fraction of hot and cold water. Typically, this fraction is 50-50; however, the hot-to-cold ratios can range from 60-40 to 40-60. Variation in inlet temperature also affects overall water temperature. The cold water inlet temperature can vary from as low as 40°F in the winter in the North to as high as 80°F in the summer in the South. This variation in inlet temperature leads to a variation in the temperature of the warm water used in the washing cycle. The use of a thermostatically controlled valve would assure a more uniform water washing temperature and would minimize the use of hot water. Such valves are not used at present in clothes washers but could reduce energy use if employed.

Additional Options

Two design options that were not considered in the original analysis are discussed below. These are the use of electrolytic dissociation of water to allow lower water temperatures, and the use of ultrasonic vibrations for dirt removal. A prototype clothes washer with electrolytic dissociation of water has been successfully tested[1]. The goal was to reduce hot water use by substituting the electrolytic production of bleaching agents for the warming process. Commercial detergents (discussed earlier) perform better at high temperatures; however, the same hypochlorite concentration obtained by adding bleaching agents to water can be achieved at low temperatures if the agents are produced inside the machine. The bleaching action is due to the chemical reaction of the oxygen (derived from the decomposition of the hypochlorite) with the insoluble organic compounds that constitute the dirt. Together they make soluble compounds which are dissolved in the water.

The washing cycle is performed in two steps. The first is with electrolytic action, which results from adding 4gm/liter of salt at room temperature. The second stage is with a commercial detergent at a temperature of 95 to 113°F. The usual rinses, spinning, and final drainage follow. Initial tests showed that energy consumption dropped from 2.5 - 2.8 kWh per cycle to 1.3 - 1.5 kWh per cycle[2].

The addition of mechanical energy can reduce the need for hot water (or chemical energy) in the cleansing action of clothes washers. One potential method of delivering the mechanical energy is through ultrasonic vibrations that loosen and remove some of the dirt on the soiled clothes. At present, data are not available on the efficacy of this design option.

REFERENCES

1. R. Bertolino, "Washer With Electrolytic Water Dissociation", Proceedings of the Conference on Energy Conservation in Buildings, Brussels, October, 1982, D. Reidel Publishing Company.

2. R. Bertolino, "Washer With Electrolytic Water Dissociation - Supplement to Previous Report", Proceedings of the Conference on Energy Conservation in Buildings, Brussels, October, 1982, D. Reidel Publishing Company.

ENERGY CONSERVATION MEASURES FOR HUMIDIFIERS/DEHUMIDIFIERS

INTRODUCTION

Humidifiers add water vapor to an indoor space. It takes 970 Btu of energy to evaporate one pound of water at normal atmospheric pressure. The energy efficiency of a humidifier is characterized by the percentage of power input that is used to evaporate water, up to a maximum of 100%. The energy can be provided by the addition of heat to a reservoir of water or to a cool mist of water droplets. A fan is sometimes used to increase the evaporation rate of the water by increasing the velocity of air flow over a wetted surface. In a central system humidifier, the heat energy comes from the central heating system whereas, in a room humidifier, the heat source is usually the room air.

In an ultrasonic humidifier, a transducer transforms electrical energy into mechanical energy. This transducer, called a nebulizer, is a small disk that oscillates at a very high frequency and churns the water into a very fine mist. The vibration is rapid enough that it cannot be heard, thus it is called "ultrasonic". A built-in fan blows the mist out through one or more nozzles. The water droplets absorb heat energy from the room air and change from the liquid to the vapor state. Thus, sensible heat energy must be added to the room to maintain constant temperature.

The operation of a dehumidifier is similar to that of an air conditioner. Room air is drawn into the device by a fan and passes over the evaporator coil. The evaporator coil is at a low temperature due to the absorption of heat and subsequent evaporation of a refrigerant. As the room air passes over the cold coils some of the moisture condenses and is collected in a container. The dryer air passes through the condensor coils where it picks up some heat before being returned to the room. The placement of the hot coils inside the house for dehumidifiers differentiates it from an air conditioner. Heat is added to the drier air at the condenser. This prevents a lowering of the room air temperature and keeps the surface temperature of the walls and other parts of the room from getting cool enough to cause condensation of water vapor. The energy efficiency of a dehumidifier is expressed in pints of water removed from the air per kWh of energy used.

PRODUCT CLASSES

Original Classes

In this previous analysis, two classes of humidifiers and one class (see Table 15) of dehumidifiers were designated. Central system humidifiers are designed to add moisture to the air stream of a central heating system. The energy needed to evaporate water is supplied by the

central heating system. Room humidifiers sometimes have heaters, or else heat energy is taken from room air to evaporate the water used for humidification. They are portable and add moisture to a localized area of the residence. Dehumidifiers remove water vapor from an indoor space and are all placed into one class as there are no significant differences in utility or efficiency for residential dehumidifiers.

TABLE 15. PRODUCT CLASSES FOR HUMIDIFERS AND DEHUMIDIFIERS

1) Central System Humidifiers
2) Room Humidifiers
3) Dehumidifiers

New Classes

We have identified no new classes of humidifiers or dehumidifiers.

DESIGN OPTIONS

Options From Previous Analysis

In the previous analysis, DOE identified two design options that can improve the efficiency of a humidifier, these are to:

1) Add a humidistat
2) Improve fan motor efficiency (for room humidifiers only)

The first option involves adding a humidistat to control the operation of the humidifier. A desired humidity level is preset so that the humidifier will turn off when the room humidity level exceeds that preset humidity. Therefore, excessive humidity is avoided and energy consumption is minimized. Most humidifiers already incorporate humidistats.

The second strategy is to improve the fan and fan motor efficiencies. Presently, the shaded pole motor is used as a mechanical power source. This type of motor is only about 25% efficient. A capacitor-type motor is about 55% efficient due to an increased power factor. About 3 to 5% of the total energy used by a humidifier is for electricity to drive the motor, however. Therefore, even a doubling of the motor efficiency yields only a 1.5% to 2.5% gain in total energy efficiency.

Dehumidifiers use much of the same technology that room air conditioners use. The original design options for improving their energy efficiency are listed below:

1) Improve compressor efficiency
2) Improve condenser heat transfer
3) Improve fan motor efficiency
4) Improve controls

These design options are described in the section on "Energy Conservation Measures For Room Air Conditioners".

Additional Options

We have not identified any new design options for humidifiers. The additional design options for dehumidifiers are similar to those for room and central air conditioners and are described in the sections on those products. The additional design options are:

1) Variable speed compressor motors
2) Scroll compressors
3) High-performance heat transfer surfaces
4) Mixed/new refrigerants
5) Variable-speed fan motors
6) Electronic expansion valves

ENERGY CONSERVATION MEASURES FOR CENTRAL AIR CONDITIONERS INCLUDING HEAT PUMPS

INTRODUCTION

A residential-size central air conditioner is a consumer product that is powered by single-phase electric current, that has a capacity under 65,000 Btu/h, and that is not contained in a furnace whose rated capacity is above 250,000 Btu/h. This product type includes cooling-only central air conditioners and heat pumps. A heat pump is a device used for heating and cooling. In the cooling mode, it functions like a cooling-only central air conditioner.

PRODUCT CLASSES

Central Air Conditioners-Original Classes

Four central air conditioner product classes have been identified by DOE. These are shown in Table 16:

TABLE 16 PRODUCT CLASSES FOR CENTRAL AIR CONDITIONERS

1) split systems (separate indoor and outdoor units) - cooling only, capacity less than 39,000 Btu/h.
2) split systems (separate indoor and outdoor units) - cooling only, capacity greater than 39,000 Btu/h.
3) single package units - cooling only, capacity less than 39,000 Btu/h.
4) single package units - cooling only, capacity greater than 39,000 Btu/h.

The single package unit has inherent heat transfer and infiltration losses between the indoor and outdoor sections because the air flow paths are close together. The split system is subject to some inherent heat losses because of the long path the refrigerant must travel. This long path causes relatively greater refrigerant pressure drops. Therefore, the energy efficiencies of single package and split system air conditioner will differ somewhat, all other design features being equal.

New Classes

No new classes have been identified for central air conditioners.

Heat Pumps-Original Classes

DOE has previously defined three classes of heat pumps:

1) air source, split system,
2) air source, single package system, and
3) air source, split system, heating only.

New Classes

Heat pumps available today use air, water, or earth as their heat source. Because water and ground temperatures fluctuate less than air on a daily and/or seasonal basis, water- and earth-coupled heat pumps have potentially higher seasonal heating and cooling efficiencies than air-source heat pumps. Water and earth-coupled heat pumps are also both constructed with a water-to-refrigerant heat exchanger in place of the outdoor coil common on air source heat pumps. The water circulated through this heat exchanger transfers heat through tubes. Because water- and earth-coupled heat pumps are so similar, they belong together in a single class, separate from air-source heat pumps. Table 17 lists suggested classes of heat pumps. The different classes are justified because each unit has performance-related features that affect efficiency.

Single-package and split systems should remain in separate classifications, because single-package systems will be harder to enlarge as a result of their design; both evaporator and condenser coils must fit inside the single-package box.

In addition to recommending separate classes for single- and split-system air- and water/ground-source heat pumps, we suggest that heat pumps be categorized by capacity. We suggest a parallel classification to that for cooling-only central air conditioners, which divides units that have capacity less than 39,000 Btu/h from those with greater capacity.

It may be desirable to subdivide the lower-capacity class into heat pumps that have capacities greater and less than 27,000 Btu/h, since 44% of split-system, and 25% of 1984-5 single-package systems have capacities under 27,000 Btu/h.[1] These smaller-capacity units are likely to achieve higher efficiencies than units in the middle, 27,000-39,000 Btu/h, category.

The existing air-source, heating- only category should be dropped because these heat pumps are currently not in production.

Finally, we believe multi-zone heat pumps are sufficiently different from the other types to deserve a category of their own. They are very useful for consumers and can use much less energy than other pumps, because they allow the consumer to heat only specific rooms (or zones). Each room has a separate thermostat and indoor coil unit.

Table 17. Heat Pump Classes

Heat Source	Class	Capacity (Btu/h)
air	split	less than 39,000
air	split	39,000 to 65,000
air	package	less than 39,000
air	package	39,000 to 65,000
air	split, heating only**	less than 65,000
air	*package, heating only**	*less than 65,000*
air	*multi-zone**	*less than 65,000*
*Water**		*less than 39,000*
*Water**		*39,000 to 65,000*

DESIGN OPTIONS

Central air conditioners, not including heat pumps, were included in the previous engineering analysis. As noted earlier, cooling-only central air conditioners are not considered separately since they function like heat pumps in the cooling mode. The only design option suitable for heat pumps but not cooling-only central air conditioners is an improved defrost system.

Options from Previous Analysis

Options considered in the previous analysis are described below:

1) Improve heat transfer of condenser and evaporator heat exchangers by increasing the heat exchanger surface area.
2) Increase compressor efficiency by decreasing compressor size (in conjunction with option 1).
3) Improve combined fan and motor efficiency.
4) Use a two-speed compressor.

Increase Heat Exchanger Surface Area

There are several ways to increase the surface areas of the condenser and evaporator heat exchangers. These include adding more frontal area, adding tube rows, and increasing the fin density. Adding more frontal area increases the flow area, so air can more easily contact the heat exchanger's fins and tubes. The added frontal area also increases the distance that the refrigerant must flow. This longer distance increases the pressure drop on the refrigerant side of the heat

*Items in italics are new classifications under consideration.
**Class should be dropped.

exchanger if the refrigerant tubes are not recircuited in the heat exchanger. Adding more frontal area usually means increasing cabinet size, since the length and height of the unit increase.

For the outdoor coil, 25 square feet of heat exchanger area provides most of the improvement in cooling efficiency that is reasonably attainable[2]. This area is about two square feet larger than the largest heat exchanger commercially available (in 3-ton units, sold in 1985). The heating efficiency is essentially unaffected by the increase in area since the outdoor coil is already oversized, at ten square feet, when used as an evaporator in the heating mode.

Cooling efficiency is also improved when the frontal area of the indoor coil is increased. (The area of the indoor coil is much smaller than that of the outdoor coil). The cooling efficiency improves sharply with frontal area at first but levels off at about 3.5 square feet.

Another way to increase the surface area of the heat exchanger is to increase the number of tube rows. The amount of copper tubing and fin material will increase, but the overall dimensions of the heat pump chassis will remain small. A two-row coil is significantly more efficient than a single-row coil. There is little advantage to a three-row coil relative to a two-row coil. Most of the efficiency gain for the two-row coil occurs when the coil area is increased from 10 to 15 square feet.

The surface area of a heat exchanger could also be increased by increasing the fin density. The outdoor tubes (in 1985 units) had fin densities ranging from 15 to 21 fins per inch. It is unlikely that fin density will exceed 21 fins per inch because, beyond this number, more fan power is required to draw the air through the heat exchanger and frost can more easily block the air passageways. For indoor coils, most tubes have 12 to 14 fins per inch. Indoor fin densities are unlikely to increase since space is needed to allow for condensation to form and drop off the heat exchanger.

The overall heat transfer coefficient can be improved by using higher performance heat transfer surfaces for the fins; for example, by using a wavy fin design. The wavy fin design helps to break up the boundary layer of air flowing through the heat exchanger, which improves the heat transfer coefficient. Wavy fins also increase the surface area. Some manufacturers use spine fin designs.

Some Japanese equipment uses internally convoluted coil tubes to improve heat transfer. A convex louver-fin heat exchanger coil has been described; it provides a 60 to 80% improvement in the heat transfer coefficient, for a 40% increase in air side pressure drop[3]. Use of such a heat exchanger configuration would allow improved heat transfer at proportionately lower air side power requirements.

Decrease Compressor Size

In order to maintain rated capacity, compressor size must be reduced when heat exchanger preformance is increased. A lower capacity compressor is smaller, and can be used. The compressor piston displacement can be decreased by reducing the length of the stroke until the rated capacity is reached. A smaller compressor consumes less power than a large one.

Improve Fan and Fan Motor Efficiency

In a heat pump or cooling-only central air conditioner, fans are used to move air past both heat exchangers. Approximately 15 or 20% of the total energy consumed by a heat pump goes to these two fans. Small fan motors, of the size used in heat pumps and central air conditioners, have efficiencies between 55 and 80%. The mechanical efficiency of a fan can vary from 20 to 45%. Therefore, the combined total efficiency of fan plus motor varies from about 11% to 36%. Centrifugal forward curved fans can be used to achieve mechanical efficiencies of close to 45%. Split capacitor-type motors can be substituted for shaded pole motors to improve motor efficiency.

Two-Speed Compressors

Dual-speed compressors are now available from a few U.S. manufacturers. The two-speed compressor can operate at low speed when the building heating or cooling load is low, resulting in a substantially reduced power requirement. When the building load is high, the compressor switches to high-speed mode, and its capacity is increased. An outdoor temperature detector is usually used to control the mode of these two-speed compressors.

The capacity of the two-speed unit increases as the speed goes from low to high. In the heating mode, the coefficient of performance (COP) improves for the high speed. In the cooling mode however, the COP for high speed is lower than for low speed. The system is more efficient at low speed because the compressor is operating with heat exchangers that are sized for high-speed operation. Therefore, the heat exchangers are oversized for low-speed operation. With the oversized heat exchangers, the evaporating temperature is higher and the condensing temperature is lower, so the compressor operates more efficiently. The fast efficiency dropoff (with decreasing outdoor temperature) in the cooling mode at low speed is a characteristic of this two-speed compressor.

ADDITIONAL DESIGN OPTIONS

Currently, seven major design improvements have been identified: variable speed compressor motors; two-speed and variable-speed fan motors; new and/or mixed refrigerants; demand defrost systems; more efficient compressors; high-performance heat transfer surfaces; and electronic expansion valves.

Variable-Speed Compressor Motors

Variable speed electric motors to drive heat pump compressors will probably appear soon in the U.S; they are already widely used in residential heat pumps in Japan. These motors allow better matching of heating and cooling loads to heat pump capacity and, therefore, improved part-load efficiency. Proponents of variable - speed motors claim an efficiency improvement of 15% over compressors with single-speed motors. Compressor motor speed depends on source frequency; electric inverters convert power sources from the standard 60 Hz to a range of 30-110 Hz. Although other means of modulating compressor capacity are conceivable, variable-speed motors will be the quickest and easiest compressor improvement.

Two- and Variable-speed Fan Motors

Following the introduction of variable-speed compressor motors in heat pumps, the next logical step for improved capacity control would be multi-speed or variable-speed fan motors. The two-speed fan motors would be similar to the two-speed motors used in compressors, with two sets of poles (one for high speed and the other for low speed). The variable-speed fan motors would also use inverters to produce the different speeds.

New/Mixed Refrigerants

Nonazeotropic refrigerant mixtures appear to be the most promising alternative to existing refrigerants. They offer: (1) reduced compressor power for the same refrigeration capacity, and (2) capacity modulation, even though compressor displacement remains constant. In air-to-air heat pumps, the concentration of the refrigerant mixture will have to be variable so that more of the denser component of the mixture is in active circulation when outdoor temperatures are low. This concentration shift could increase capacity and COP. For instance, a nonazeotropic mixture of 65% R-13B1 and 35% R-152 improved heating COP 11% and 28%, at -8.3 C and -17.8 C, respectively, compared to R-22. New azeotropic mixtures may also offer improved performance for both cooling and heating.

Use Demand Defrost Control Systems

This design option is applicable to heat pumps only, not to central air conditioners. When outside temperatures approach 32°F, the outside coil of a heat pump can ice over as moisture condenses onto the cold surfaces. The layer of ice reduces the heat exchanger's effectiveness. Therefore, heat pumps have traditionally employed a timer which periodically signals the heat pump to pass warm air from inside the house over the outdoor coils. Studies have shown that, with this conventional timer control, 27% of defrosts occur when no frost build-up is likely[4]. Demand defrost controls, which switch over to defrost mode only when necessary, are now employed in many high-performance heat pumps. Two different procedures are being used to

initiate the defrost cycle. In one case the air-side pressure drop across the outdoor coil is measured; the defrost cycle is initiated when the pressure drops to a specified level. Another method measures the temperature difference between the outdoor coil tube surface and the outdoor air, and initiates the defrost cycle once the temperature difference exceeds a predetermined figure. Microprocessors can be used to implement these demand defrost strategies. Imaiida reported a 5% improvement in heating seasonal performance factor (HSPF) with demand control relative to time control (for the Tokyo climate)[5].

Increase Compressor Efficiency

The efficiency of the compressor can be increased either by using a more efficient motor to drive the device or by increasing the intrinsic efficiency of the compressor itself. The efficiency of electric motors that drive compressors varies from about 80 to 88%. It may be possible to improve motor efficiency to about 92%[6]. Compressors can be reciprocating, rotary, or centrifugal. Most residential-sized heat pumps manufactured in the U.S. use reciprocating compressors for the refrigerant vapor. One U.S. and several Japanese manufacturers also use rotary compressors in their heat pumps. Rotary or scroll compressors have a higher adiabatic efficiency and a greater capacity per unit weight than reciprocating compressors. Low-capacity rotary models are now available from U.S. manufacturers and low-capacity Japanese models are nearly all rotary.

Senshu reported a scroll-type compressor that provides a 10% adiabatic efficiency improvement while being 40% smaller and 15% lighter than an equivalent reciprocating type[3]. The scroll compressor's main components are two identical involute spiral scrolls. One of the scrolls is fixed, and the other orbits around the center of the fixed scroll. The major advantages of the scroll design are the reduced clearance volume, reduced refrigerant/lubrication interaction, lower inertia, and lower valve leakage and dynamic losses (no valves are required) relative to reciprocating compressors. Senshu reported an efficiency improvement of about 8% over a similar reciprocating compressor.

High-performance Heat Transfer Surfaces

High-performance heat transfer surfaces include perforated plate fins and high-density spine fins that can transfer more energy per unit area than current surfaces. Internal fins in refrigerant tubes are also possible, and currently used in many commercial-size chillers.

Electronic Expansion Valves

The electronic expansion valve should make it possible to obtain better control of flow conditions (degree of superheat at the outlet of the evaporator, subcooling at the outlet of the condenser, etc.) than that which can be obtained with either a thermostatic expansion valve or capillary tubes. Some electronic valves have an electric motor whose rotation is converted by gears

into vertical movement. Another design uses a solenoid to drive a plunger that controls the flow opening. Either design would employ an electronic microprocessor, which would send a signal to the valve to open or close more, depending on the conditions that the valve sensed. This technology is currently used on room air conditioners and heat pumps in Japan. Expected efficiency improvements should be near 10% for both heating and cooling. These valves should also allow for shorter defrost times, and be more reliable than conventional expansion devices.

REFERENCES

1. "Comparative Study of Energy Efficiency Ratios", Air Conditioning and Refrigeration Institute, April 1985, Arlington VA.

2. D. O'Neal et al, "An Analysis of Efficiency Improvements for Residential Sized Heat Pumps", Texas A&M University, College Station TX, May 1986.

3. Senshu et al, "Annual Energy Saving Effect of Capacity Modulated Air Conditioner Equipped with Inverter Driven Scroll Compressor", ASHRAE Technical Data Bulletin, June 1985.

4. V. E. Baxter and J. C. Moyers, "Field Measured Cycling, Frosting, and Defrosting Losses for a High Efficiency Air Source Heat Pump", ASHRAE Technical Data Bulletin, June 1985.

5. T. Imaiida et al, "Development of Demand Defrost Control System for Residential Heat Pumps", ASHRAE Technical Data Bulletin, June 1985.

6. "Present and Projected Efficiency Improvements in Central Air Conditioners and Heat Pumps", DHR Incorporated, DHR C5133-23, McLean VA, December 1985.

ENERGY CONSERVATION MEASURES FOR FURNACES AND BOILERS

INTRODUCTION

A "furnace" is defined as a device designed to be the principal heating source for a central heat distribution system used for the living space of a residence, having a heat input rate less than 300,000 Btu/h for electric boilers and low-pressure steam or hot water boilers, or 225,000 Btu/h for forced-air central furnaces, gravity central furnaces and electric central furnaces.

Within this product type, a distinction is made between a "furnace", where the heating medium is air, and a "boiler", where the heating medium is water or steam. Furnaces and boilers can be electrically powered, gas-fired or oil-fired.

PRODUCT CLASSES

Original Classes

Twelve classes of furnaces were specified by DOE in the 1982 Standards Document. These classes are distinguished either by the type of fuel consumed or by performance-related features which affect utility and efficiency.

Table 18 shows the features of these products that are used to define the various product classes. Table 19 lists the twelve existing product classes (as of 1982).

TABLE 18.

Furnace/Boiler Features Used to Delineate Product Classes

Energy Form Utilized	Heat Medium	Circulation System	Installation Location	Configuration
Electricity	Air (furnaces)	Forced	Indoor	Vertical
Gas ——— Oil	Steam or Water (Boilers)	Gravity	Outdoor	Horizontal

*Items in italics are new classifications under consideration.

TABLE 19. Original DOE Product Classes - Furnaces and Boilers

1) Gas Furnace, indoor
2) Gas Boiler, indoor
3) Oil Furnace, indoor
4) Oil Boiler, indoor
5) Gas Furnace, direct vent (outdoor air but nonweatherproof)
6) Gas Furnace, outdoor
7) Oil Furnace, outdoor
8) Electric Furnace
9) Gas Furnace, Gravity
10) Gas Boiler, outdoor
11) Gas Boiler, indoor finned tube
12) Oil Boiler, outdoor
13) *Oil Furnace, direct vent**
14) *Gas Furnace, two stage burner**
15) *Integrated space and water heating system**

Basic models of furnaces are segregated according to whether they use electricity, gas, or oil to produce heat. The energy efficiencies of electric, gas, or oil furnaces are inherently different. Electricity is converted to heat with essentially 100% efficiency, whereas both gas and oil furnaces have efficiencies less than 100% because of their flue losses. The flue losses tend to be about 3% higher for gas furnaces than for oil, because more water vapor is generated by the gas combustion process and is subsequently lost up the flue. Thus, the latent energy losses are inherently higher for a gas furnace. Failure to establish separate classes according to the type of fuel used may result in the elimination of basic models using a certain type of fuel.

One performance-related feature which affects the utility of a boiler/furnace is the method of heat distribution to the household. Included in this product type are (a) boilers, which distribute heat by either low-pressure steam (15 pounds per square inch or less steam pressure) or hot water, and (b) furnaces, which distribute heat using warm air.

Forced-air furnaces offer the utility of being suitable for use with central air conditioners, central humidifiers, and central air cleaners (filters and/or electrostatic precipitators). Boilers offer the utility of having a distribution system which generally requires less space than air distribution systems; that is, the pipes require less space than air ducts.

Gas furnaces use air circulation systems driven either by buoyancy (gravity) or by a blower (forced air). Gravity-type systems offer the utility of operating without an electrical connection. The efficiency of gravity gas furnaces tends to be lower than the efficiency of forced-air gas furnaces, so a separate class was established by DOE for gravity gas furnaces. A class of oil furnaces using gravity to circulate hot air was not specified, because DOE was not aware of any such

units being sold.

Another distinct performance-related feature which affects utility is whether the furnace is installed indoors or outdoors. In the test procedures, units designed for outdoor installation have their jacket heat losses evaluated and these losses are deducted from the efficiency rating. This efficiency deduction is justified by the architectural utility that may be afforded a consumer by outdoor basic models.

Another performance-related feature which affects utility is the horizontal configuration of some models of forced-air furnaces. This horizontal configuration results in less efficient heat transfer due to shorter heat exchangers than other configurations, but has the utility of being uniquely adaptable to attics and crawl spaces. Since these horizontal furnaces are installed indoors in unheated spaces, they must be insulated but need not be weatherized. A separate class of gas horizontal furnaces is proposed to prevent the possible elimination of this type of configuration.

Outdoor units, either vertical or horizontal, with weatherproofed cabinets, have fewer dimensional constraints than the nonweatherproofed, horizontal units discussed above. Therefore, their efficiency can be higher than the nonweatherized horizontal units and only outdoor, nonweatherproofed, horizontal furnaces are identified as those having justifiable reduced performance. However, their jacket heat losses are not recoverable as are those of indoor units.

New Classes

Classes 9, 10, 11, and 12, in aggregate account for less than one-half of one percent of gas and oil furnace and boiler sales. It should also be noted that direct-vent oil furnaces are sold by many manufacturers and may require a separate product class.

In the eight years since 1978, when DOE segregated furnaces and boilers into separate classes to which different energy efficiency standards would apply, many new furnace/boiler products have been introduced. These new products incorporate new technologies and features designed either to increase energy efficiency or make the furnace or boiler more useful, including:

- pulsed combustion (gas furnaces),
- two-stage burners (gas) and modulating burners (oil),
- condensing heat exchangers (gas and oil, furnaces and boilers),
- computer controls for furnaces and boilers (gas and oil),
- heat pipes (gas),
- multi-fuel gas/oil capability,
- integrated space heating/water heating systems,

- induced draft or power burners (gas furnaces and boilers), and
- very low input (40,000 Btu/h) for gas furnaces.

Obviously, most of these new products could be placed into the existing DOE classes. However, in certain cases there may be sufficient justification for a new product class. One such class might be the integrated heating systems, although others may also be of interest. At this time, additional analysis is needed before a decision is made on product classes.

DESIGN OPTIONS

Current industry data indicate that the 1983, 1984, 1985 sales weighted average AFUE of gas indoor furnaces shipped were 69%, 73% and 76% compared to the 1978 estimated average of 64.5%. Efficiency increases of boiler product classes during this same time period are comparable. It is not inconceivable that by 1988 the most popular furnace will have an AFUE above 80%. Significant reductions in residential heating load have been achieved through increased insulation and reduced infiltration. Manufacturers are now offering furnaces in the 30-40 MBtu/h range, which targets this lower heating load market. These furnaces incorporate the same energy-saving features mentioned above. They do not constitute a new product class but must be considered when reevaluating the baseline.

Options from Previous Analysis

Six design options for improving the efficiency of furnaces and boilers were evaluated. These were:

1) *Increased Heat Exchanger Surface Area*

   This design option involves increasing the size of the heat exchanger to improve heat recovery. It can be utilized in both gas-fired and oil-fired furnaces and boilers.

2) *Intermittent Ignition Device (IID)*

   Intermittent ignition devices are used in gas-fired furnaces in place of pilots. The IID's require electrical hookup.

3) *Stack Damper*

   Stack dampers are used to reduce losses during the standby period. A stack damper is electrically powered and wired into the control system so that it opens prior to the firing of the furnace or boiler and closes after the firing period is terminated.

4) *Power Burner or Power Vent*

This design option applies to gas-fired units. It involves using a power blower on the inlet or exit side of the unit to promote flow of the combustion products through the heat exchanger. This option permits higher combustion efficiency and reduced standby losses.

5) *Increased Insulation*

On outdoor units, jacket losses are reduced by adding insulation. Existing insulation is replaced with a denser fiberglass having the same thickness as the original insulation.

6) *Condensing Heat Exchanger*

The use of corrosion-resistant heat exchangers and vent piping has led to furnaces and boilers operating in the near condensing (84-88%) and condensing (90-96%) ranges.

Since the original standards were proposed, manufacturers have incorporated all these design options into their product lines and, in many cases, have exceeded the expected efficiency improvements. One of the most popular combinations of options for gas furnaces has been a high-efficiency incorporation of a heat exchanger, IID, and power vent. This type of furnace is now offered by many manufacturers, and most versions have an AFUE in the 78-81% range.

Additional Options

Additional design options suggested in connection with a revised analysis of standard for furnaces and boilers are as follows:

1) *Additional Improvement of Steady-State Efficiency* - Improvement in the steady-state efficiency of a furnace can be achieved by 1) reducing the excess air for the combustion of the fuel, 2) increasing the heat exchanger area per unit mass of heat input, or 3) improving the effectiveness of the heat exchanger; that is, the heat-transfer rate from the products of combustion to the heating medium (air or water). Further improvement in steady-state efficiency by combining all three design options together was not considered in the original analyses.

2) *Two-Stage and Modulating Burners* - Another energy-saving strategy is to operate during the heating season at reduced firing rate for longer periods. This reduces the period during which off-cycle losses can occur, and may increase the off-period efficiency.

ACKNOWLEDGMENTS

This work was suppported by the U.S. Department of Energy, Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Equipment Division, under contract DE-AC03-76SF00098. Arthur D. Little, provided survey reports on refrigerator/freezers, freezers, clothes dryers, furnaces, room air conditioners, and ranges and ovens. Parts of these reports were incorporated into this document. The individual authors are: Richard N. Caron, furnaces, W. Thompson Lawrence, ranges and ovens and clothes dryers, W. David Lee, room air conditioners, and Richard F. Topping, refrigerator/freezers and freezers. Much of the section on central air conditioners (including heat pumps) was derived from, "An Analysis of Efficiency Improvements in Residential Sized Heat Pumps", by Dennis L. O'Neal, Curtis L. Boecker, William E. Murphy, and James R. Notman. The author thanks Mark Levine, James McMahon, and Henry Ruderman of Lawrence Berkeley Laboratory for their thoughtful reviews. Barry Berlin, Michael McCabe, and John Talbot, of the Department of Energy, provided very useful comments that were incorporated into this final version. Other helpful reviews were received from Howard Geller, of the American Council for an Energy Efficient Economy (ACEEE), David Goldstein, of the Natural Resources Defense Council (NRDC), and Michael Messenger, of the California Energy Commission.

Alan Meier, of Lawrence Berkeley Laboratory, Tom Lawrence, of Arthur D. Little, and Frank Stanonick, of the Gas Appliance Manufacturers Association (GAMA), provided many useful suggestions for the section on water heaters. Dennis O'Neal, of Texas A&M University, thoroughly reviewed the section on central air conditioners, including heat pumps. David Ross, of Policy Research Associates, provided useful reviews of the sections on clothes washers, dishwashers, televisions, humidifiers, and dehumidifiers. While we acknowledge support received from the above sources, any errors or omissions are the responsibility of the author.

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720