Energy Saving Technologies in Home Appliances

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OVERVIEW: The environmental friendliness of home appliances can be addressed in three fundamental ways: global environment preservation (prevent global warming and protect the ozone layer), resource recycling (the Three Rs: reduce, reuse, recycle), and chemical substance management (reducing use of chemicals in products and manufacturing processes that adversely affect the environment). Now that the first commitment period to achieve CO_2 reduction targets under the Kyoto Protocol has begun (2008–2012), prevention of global warming in particular has drawn a great deal of attention and emerged as a critical international political issue. Residential sector currently accounts for 13.5% of Japan's CO_2 emissions, and many anticipate that more energy efficient appliances will help reduce the country's CO_2 emissions. To meet these public expectations and needs, Hitachi Appliances, Inc. is committed to the development of the most energy efficient home appliances that are available.

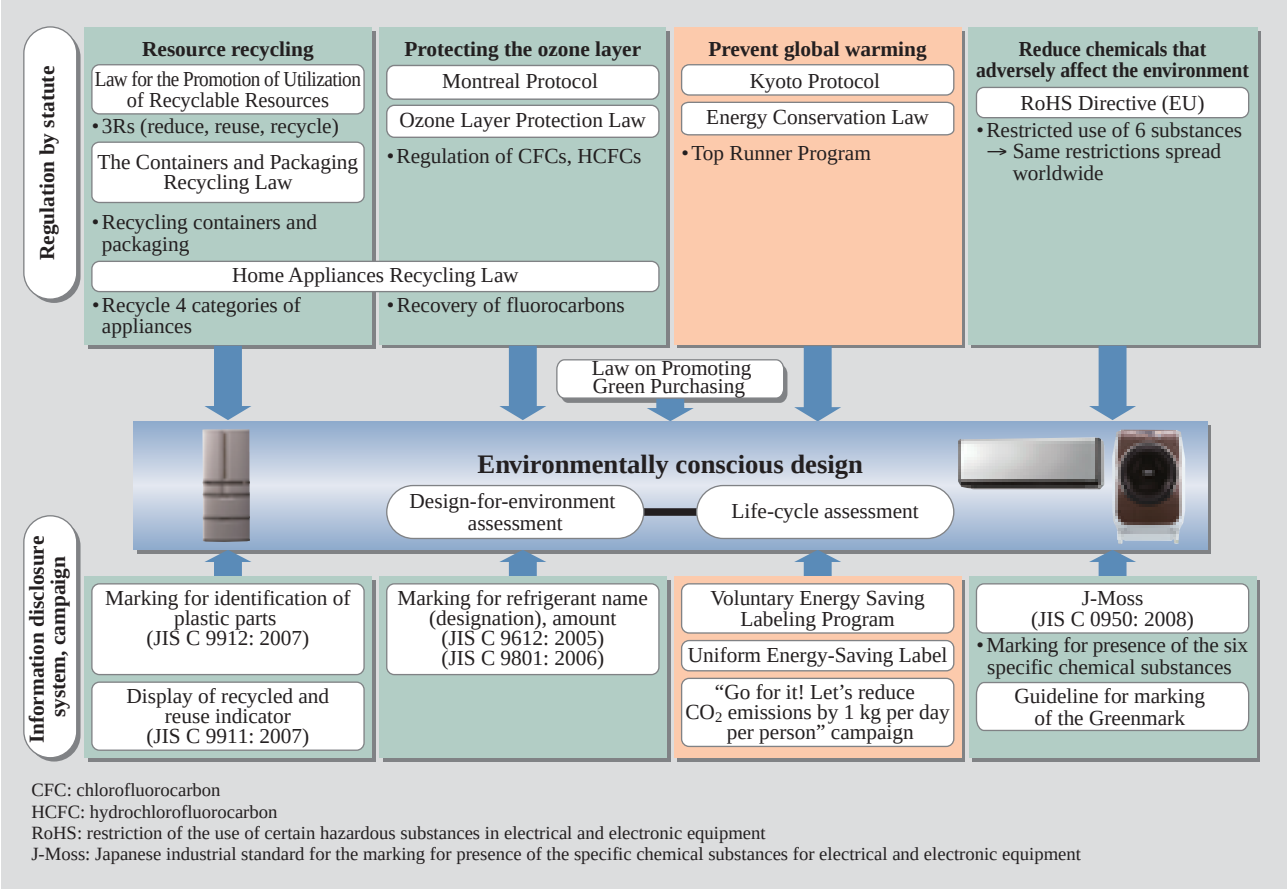
INTRODUCTION

SIGNIFICANT steps began to be made toward making home appliances more environmentally friendly in the early 1990s in the face of growing mountains of end-of-life appliances and electronics. Design-for-environment assessments have become routine when designing new products and every effort has been made to make products easy to disassemble, consolidate different kinds of materials, and other initiatives in compliance with the "Resource Recycling Promotion Law" enacted in 1991 that was subsequently revised and enacted as the "Law for the Promotion of Utilization of Recyclable Resources" in 2001. In a parallel development, we are moving quickly to replace ozone-depleting banned CFC (chlorofluorocarbon) refrigerant with environmentally benign HCFC (hydrochlorofluorocarbon) and HFC (hydrofluorocarbon) in refrigerators, room air conditioners, and other appliances.

Improving the energy efficiency of consumer products is critical for mitigating global warming. After the United Nations Framework Convention on Climate Change went into effect in 1994, industrialized nations around the globe committed themselves under the terms of the Kyoto Protocol to numerical greenhouse gas emission reduction targets at COP3 [Third Conference of the Parties (Kyoto)], recognizing that conservation of energy is not merely a consumer cost merit concern, but rather is a critically important issue affecting the whole planet that must be addressed at the national and international levels. This being the first year of the first five-year commitment period (2008–2012), public and private sectors alike have stepped up efforts as shown schematically in Fig. 1 to achieve their reduction targets.

Japan produces close to 1.36 billion tons of greenhouse gas emissions a year (CO_2 equivalents in 2005), of which about 1.29 billion tons are CO_2 emissions, and thus accounts for about 4.8% of the world's CO_2 emissions. Indirect emissions of residential sector account for roughly 13.5% of Japan's total emissions, so each individual produces about 2.2 t and each household produces approximately 5.5 t of CO_2 emissions per year. As one can see in Fig. 2, close to 40% of these emissions are attributed to power consumption, and a substantial portion of this figure comes from room air conditioners and refrigerators, as much as 25% and 16%, respectively.

The government has mobilized a nationwide effort starting with the "Go for it! Let's reduce CO_2 emissions by 1 kg per day per person" campaign in June 2007, and establishment of the Energy-Efficient Household Appliance Promotion Forum bringing together appliance manufacturers, retailers, and consumer

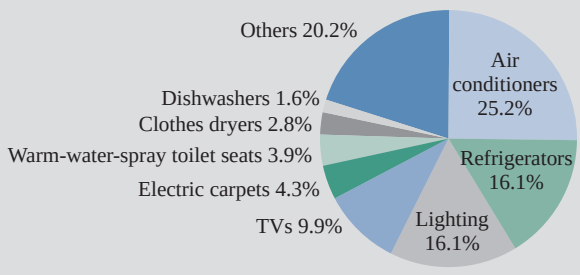


CFC: chlorofluorocarbon
HCFC: hydrochlorofluorocarbon
RoHS: restriction of the use of certain hazardous substances in electrical and electronic equipment
J-Moss: Japanese industrial standard for the marking for presence of the specific chemical substances for electrical and electronic equipment

Fig. 1—Environmental Developments Affecting Home Appliances.
Addressing a range of issues — resource recycling, chemical substances that adversely affect the environment, etc. — seeking better energy efficiency to prevent global warming is given greater weight. A range of initiatives is promoting greater dissemination of energy-efficient home appliances: the voluntary Energy Saving Labeling Program, the Energy Conservation Grand Prize for excellent energy conservation equipment, the Energy Efficient Product Retailer Assessment System, and so on.

groups a few months later in October 2007.

Hitachi Appliances, Inc. has committed substantial resources and effort into developing superior energy-efficient environmentally friendly green appliances in line with these nationwide societal trends.



Source: Agency for Natural Resources and Energy "Overview of Demand and Supply for Electricity 2004" (in Japanese, as projected in 2003).
Note: Percentages are rounded off so the total is not 100%.

Fig. 2—Comparison of Power Consumption in Households.
CO_2 emissions by power consumption accounts for close to 40% of emissions derived from household in Japan, and percentages from air conditioners and refrigerators are particularly high.

The focal point of energy-saving advances in appliances is the motor drive, and Hitachi was one of the first to begin research and development of inverter control and PAM (pulse amplitude modulation) control for appliances, and has made excellent headway with these technologies right up to the present day. Hitachi also has incorporated many energy-saving constituent technologies in its appliance products, and in recognition of its eco initiatives, was awarded the Chairman Prizes of The Energy Conservation Center, Japan (ECCJ) — the Energy Conservation Grand Prize — for both its refrigerators (R-X6000 and seven other models) and room air conditioners (RAS-S40X2 and three other models) in 2007 (all prize-winning models are for the Japanese market).

In this paper we will provide a summary overview of the latest energy-saving technologies incorporated

Fig. 3—R-X6000 Model Refrigerator Featuring a Mid-freezer Layout and Vacuum Compartment.
Not only features a vacuum compartment that preserves the nutritional value of perishable foods, but also substantial 601 L of capacity.

in Hitachi's refrigerators and room air conditioners for Japanese market.

ENERGY-EFFICIENT REFRIGERATORS

What Consumers Want in Refrigerators

While the total demand for refrigerators is roughly 4.5 million per year in Japan, by far the greatest demand is for models with a rated capacity of 500 L or more, so it is clear that consumers are looking for large-capacity models that are also energy efficient. Consumers have also shown greater concern about health in recent years, so more and more people are looking for a refrigerator that keeps perishable foods fresher and longer. To address these needs, we developed the series of household refrigerators illustrated in Fig. 3 featuring a vacuum compartment and mid-freezer layout.

Primary Energy-saving Technologies

(1) Mid-freezer layout

It was found that the mid-freezer layout shown in Fig. 4 (a) saved considerable space for the capacity and energy consumption compared to the layout shown in Fig. 4 (b) with the vegetable compartment located in the middle. A particular advantage of the mid-freezer layout is that it locates the freezer compartment farther from the compressor and closer to the evaporator, which minimizes losses from heat leaks and enables the walls to be made thinner. Locating the freezer compartment in the middle also permits the freezer air to be focused on freezer, which reduces freezer air

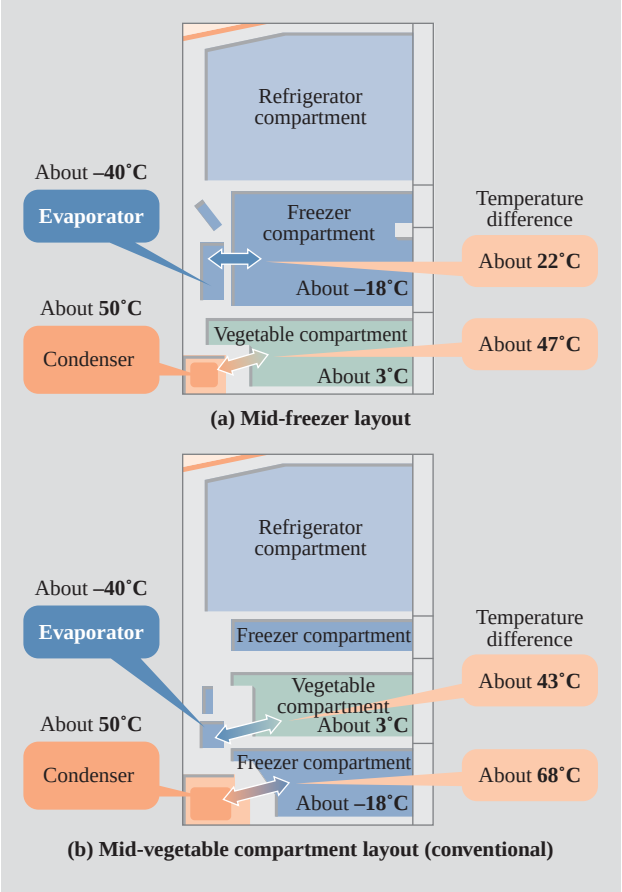


Fig. 4—Comparison of Refrigerator and Freezer Structures (cross section).
The advantage of the mid-freezer layout is that it locates the freezer compartment farther from the high-temperature compressor and closer to the low-temperature evaporator, and thus improves cooling efficiency.

circulation resistance and improves cooling efficiency, and saves energy consumption more effectively.

(2) New outer wall structure

The outer case of the new refrigerator has also been redesigned as shown in Fig. 5, so the side and top panels are integrally formed from a single sheet. This strengthens the entire chassis of the refrigerator, thus reducing the need for structural support material so the walls for the refrigerator can be made thinner. This integrated side and top one-piece structure also allows the heat dissipating pipes to be mounted in the ceiling where heat dissipation efficiency is best. Shaped VIPs (vacuum insulated panels) are installed beneath the heat-dissipation pipes and the control panel housing to achieve a very efficient heat-dissipation structure. VIPs on the sides of the refrigerator have also been bolstered to further power consumption.

(3) Shaped vacuum insulated panels

VIPs are produced by vacuum packaging an

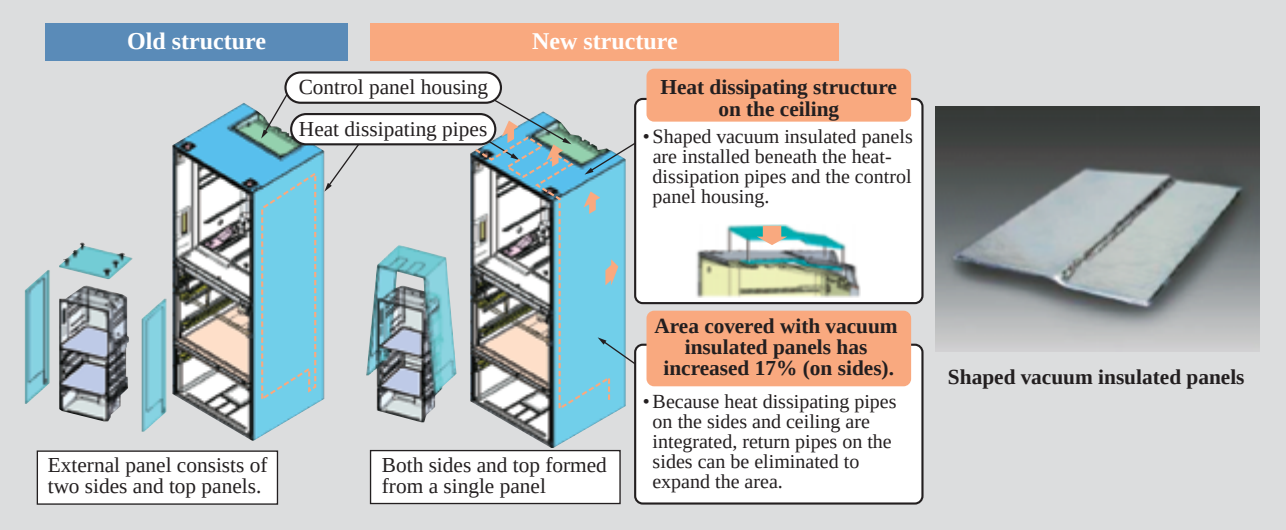


Fig. 5—New External Panel Structure and Shaped Vacuum Insulated Panels.
Side and top panels are formed from a single sheet for improved strength and heat dissipation efficiency.

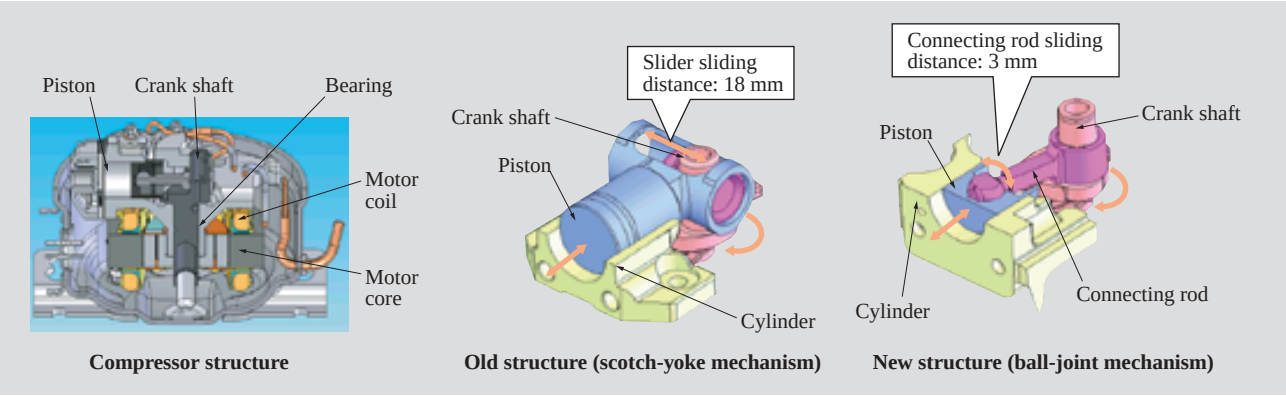


Fig. 6—Compressor Piston Connecting Rod Assembly.
The connecting rod sliding distance is shortened using the ball joint mechanism, and this reduces energy losses caused by the sliding.

insulating core material in gas barrier bag, and represent a key technology for many applications including use as a construction material in the fight against global warming. Anticipating that VIPs would emerge as critical technology, Hitachi made the necessary investment in plant and equipment and began to develop original technology about five years ago. As a result, Hitachi succeeded in developing VIPs with the highest level insulation efficiency in the world. For this particular refrigerator, the insulation efficiency has been substantially improved over previous models by increasing the vacuum of the VIPs. Referring again to Fig. 5, we are now beginning to adopt the most recently developed "shaped VIPs" that conform to irregularities inside the refrigerator chassis. We are now able to apply VIPs to the ceiling where we couldn't before due to the protruding control panel housing.

(4) High-performance compact compressor

Efficiency of the compressor was improved as illustrated in Fig. 6 by replacing the conventional scotch-yoke mechanism with the ball joint in the piston's connecting rod assembly. This shortens the sliding distance from 18 mm to 3 mm, thus reducing sliding losses. Hitachi's compressor has the best COP (coefficient of performance: refrigerating capacity divided by the input power) in the industry as a result of several refinements — optimum discharge valve structure, more precise bearing, and optimum motor control — and helps hold down the power consumption of our refrigerators. And by reengineering the ball-joint assembly, we were able to integrate the frame and cylinder as a single piece to implement the

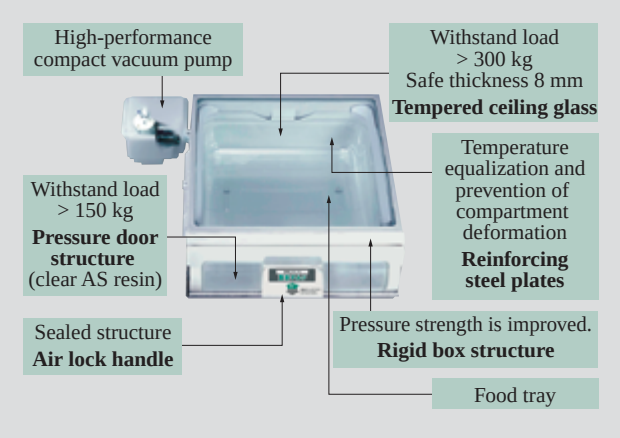


Fig. 7—Vacuum Pressure Compartment.
Pressure in the compartment is reduced to about 0.7 atm in air, thus preventing loss of nutrients in perishable foods due to oxidation.

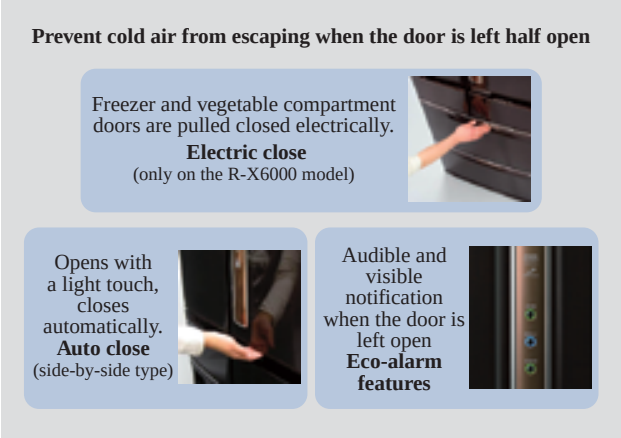


Fig. 8—Function to Prevent Doors Being Left Open.
Preventing cold air from being lost when the door is left open contributes to better energy efficiency.

compressor much more compactly and create more space in the refrigerator.

(5) Multiple sensors

The refrigerator has a total of seven sensors to control the heaters in each of the compartments. To minimize the power input to the various heaters, two out of the seven sensors track temperature data. This enables more precise temperature control and reduced power consumption. One heater is used to prevent the water supply line to the ice maker from freezing. Noting that the feedwater pump electrical current varies depending on whether water is in the supply tank or not, a sensor determines whether water is in the tank by comparing the electrical current when the pump is running normally or in reverse. Then by implementing controls so power input to the heater is reduced when there is no water in the tank, the power consumption is reduced.

(6) Other energy-saving technologies

Adopting an original vacuum preservation system developed by Hitachi, Hitachi was the first company in the world to offer a refrigerator featuring a vacuum compartment (shown schematically in Fig. 7) in the bottom of refrigerator compartment. The pressure compartment is sealed with an air lock handle and reduced to about 0.7 atm (atmospheres) in air, the optimum pressure for preserving the nutritional value of perishable foods with the least loss of DHA (docosahexaenoic acid), vitamins, and amino acids. The compartment is effectively sealed by closing the door, and because the compartment is indirectly cooled, reduction in moisture, rise in temperature from opening and closing the refrigerator door, and power consumption for additional chilling are all suppressed.

A lot of cold air is lost when refrigerator door is inadvertently left open, and even when this happens at irregular intervals, it can practically eliminate all the energy-saving effects. To make sure this doesn't happen, Fig. 8 shows that the R-X6000 model is equipped with a feature so the lower freezer and vegetable compartment drawer doors close electrically. And the side-by-side and French-door models come with a feature that closes the door or doors automatically from the inside if one of the doors is left open (see Fig. 8).

Every model of the series also features an audible "eco-alarm" that sounds if the automatic retractable door-closer is not able to close the door within one minute, and three LEDs (light emitting diodes), one each for the refrigerator compartment, the vacuum compartment, and the rapid freezing compartment, on the door of the refrigerator compartment that flash on and off to show visually that the compartment doors have been open left. Finally, the use of R600a (isobutene) as a refrigerant that has no adverse effect on ozone and virtually no effect on global warming in combination with cyclopentane as the insulation foaming agent results in non-HFC refrigerators that are truly environmentally benign.

Energy-saving Effects

Thanks to the technologies highlighted in this section, Hitachi's R-S45XM model was rated the most energy-efficient freezer/refrigerator in the rated capacity class of 451 L or more, and the R-S42XM was designated the most energy-efficient model

refrigerator in the 401–450-L rated capacity that is currently available on the Japanese market (as of October 25, 2007). The R-X6000 model has 6% greater capacity than last year's R-W5700 with almost the same outside dimensions, yet uses close to 20% less energy even though it is one of the largest capacity household refrigerators (601 L) that is available as of September 10, 2007 (the R-X6000 consumes about 490 kWh/year measured as specified in JIS C9801: 2006, or 125% of the energy efficiency standard achievement percentage to the target at 2010 based on the Energy Conservation Law of Japan).

Fig. 9—PAM (pulse amplitude modulation) Air Conditioner (X series) Moisturizing the Skin Using Ion Mist (RAS-X40X2). Featuring advanced air-purifying functions, the air conditioner provides a very high quality room environment. The front panel opens up when the air conditioner is turned on (right photo).

ENERGY-EFFICIENT ROOM AIR CONDITIONERS

What Consumers Want in Room Air Conditioners

The 2007 estimated market for room air conditioners in Japan was 7.2 million units. Since air conditioners consume more power than any other appliance in the house, the number one thing consumers want in an air conditioner is that cost less to operate — in other words, that it offers improved energy efficiency. Currently, 51% of total air conditioners sold are to replace older models, which dictates that new models must conform to the standard width dimension of less than 80 cm for indoor air conditioners. This was taken into account in developing Hitachi's current lineup of air conditioners illustrated in Fig. 9: the X series split-type air conditioners (indoor body width = 87.5 cm) and the S series split-type models (indoor unit width = 79.5 cm) for Japanese market.

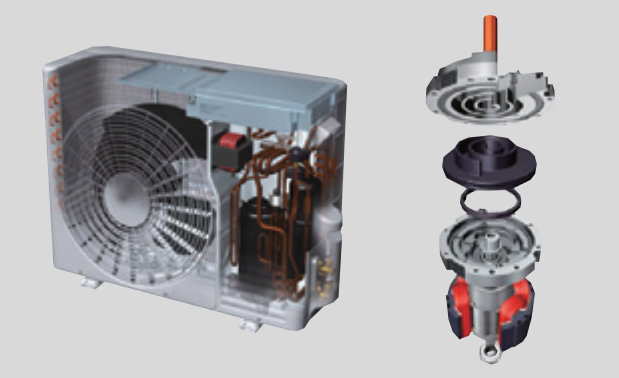


Fig. 10—Outdoor Unit of Room Air Conditioner and Cut-away View of Scroll Compressor.
The scroll compressor consists of two spiral blades — a fixed scroll and a rotating scroll — that smoothly rotates, and intakes, compresses, and discharges processes occuring simultaneously. Advantages of the scroll compressor are high efficiency, low vibration, and low noise.

Primary Energy-saving Technologies

A room air conditioner essentially has the same configuration as a heat pump, so improving the energy efficiency of an air conditioner is tantamount to reducing the energy consumption of the basic elements of a heat pump: the compressor, the compressor drive control circuit, the heat exchanger, and the air blast performance. The index of energy efficiency has recently undergone a change from COP under specified weather conditions to the APF (annual performance factor). With the goal of elevating the APF of air conditioners, emphasis has especially focused on improving efficiency at medium capacity (half the rated capacity). It has been found that the relative importance efficiency at the medium capacity accounts for about 75% of a room air conditioner's APF.

(1) Compressor and compressor drive control circuit

The power consumption of the compressor that compresses the refrigerant as it cycles through the refrigerating cycle accounts for close to 80% of the power consumed by the air conditioner, so enhancing the efficiency of the compressor is exceedingly important. Improving compression efficiency is tantamount to reducing various losses associated with compression of the refrigerant: friction losses (losses generated by the sliding of bearings and other mechanical parts), leakage losses (losses caused when refrigerant migrates from high-pressure regions to low-pressure regions), over-compression and reexpansion losses (losses produced when compression exceeds the theoretical adiabatic compression line), and motor losses (copper and iron losses). We have had good success in reducing these various losses in the past, but the primary emphasis of recent efforts has been on improving medium capacity energy efficiency.

As one can see in Fig. 10, Hitachi's energy-efficient

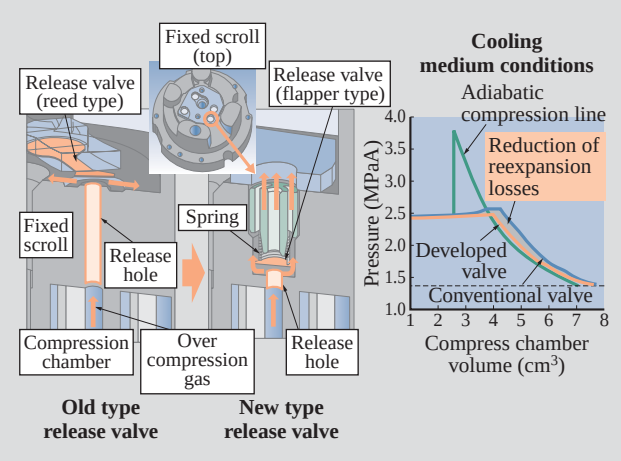


Fig. 11—Scroll Compressor's New Release Valve. The release valve developed in this work eliminates dead volume, prevents over compression, and substantially reduces reexpansion losses.

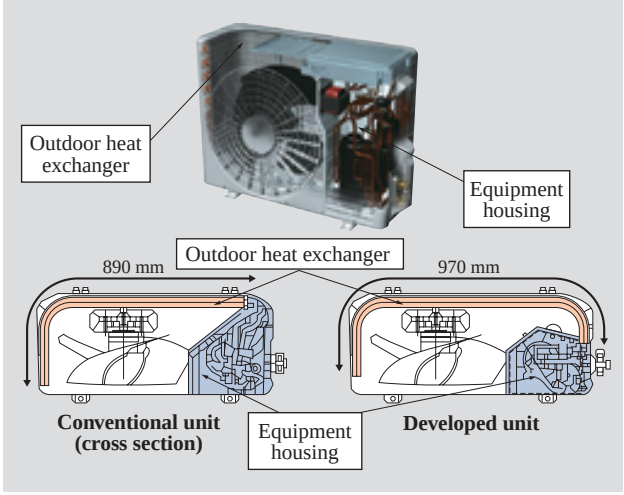


Fig. 12—Improvement of Outdoor Heat Exchangers. Volume of the equipment housing is reduced, and the heat exchanger surface is expanded by about 9%.

room air conditioners employ a compact scroll-type compressor. The main performance drawback for scroll compressors in the medium-capacity range is over compression and reexpansion losses. To address these issues, we developed a new release valve that effectively prevents over compression while at the same time greatly reducing the reexpansion losses. As one can see from the comparison between the old and the new release values in Fig. 11, the key difference is the newly designed mechanism in the new valve that substantially reduces the dead volume in the old valve. In addition, friction losses with rotation are significantly reduced as a result of expanded displacement, and this improves the APF by 2.5%.

To reduce motor losses, we improved lamination thickness by about 22% and engineered the core shape to reduce current distortion. Moreover, compressor drive control circuit losses at medium capacity make up most of the control circuit fixed losses and have a major adverse effect on compressor motor current, so figuring out a way to reduce the compressor current for medium capacity was a major concern. We addressed this challenge by precisely determining the torque required by the compressor motor, then redesigning the motor coil to minimize the motor current within medium-capacity range. This yielded a total improvement gain for both the compressor motor and compressor drive control circuit of approximately 2%.

(2) Heat exchanger

Recent work on indoor heat exchangers has yielded 17% increased heating area with efficient positioning, so the auxiliary heat exchanger equalizes the ventilation resistance. Turning to outdoor heat exchangers, by exploiting lower vibration property of the scroll compressor, we were able to reduce the refrigerant lines and reduce the volume of the equipment housing and increase the area of the heat exchanger by about 9% by using the extra space, as shown in Fig. 12.

(3) Air blast performance (indoor equipment)

Ventilation resistance was reduced by making the

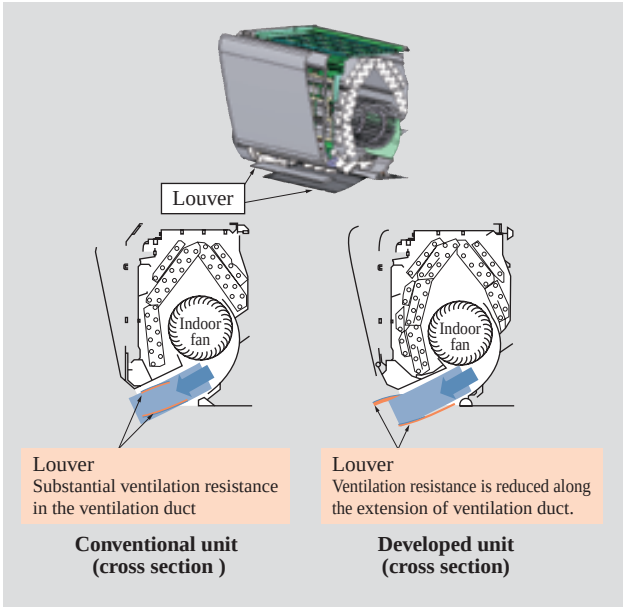


Fig. 13—Reduced Ventilation Resistance of Indoor Unit. Ventilation resistance and air blasting power are reduced, while more pleasant air flow control is achieved.

upper louvers in the blowout opening wing-shaped and repositioning them away from inside the ventilation duct as before to near the blowout opening, as illustrated in Fig. 13. This not only permitted a reduction in the air blasting power, it also provides far more pleasant airflow control than in the past: warm floor-level airflow that fully reaches people's feet, and a very gentle horizontal flow of cool air instead of the intense blast of air that people experienced in the past.

(4) Energy-saving auto air-filter cleaning function

Adoption of an auto air-filter cleaning function yields a 30% energy saving compared to when an air conditioner filter is manually cleaned only once a year.

Energy-saving Effects

Thanks to these various innovations and technical refinements, Hitachi's S-series air conditioners with an APF rating of 5.8 and X-series models with an APF rating of 6.2 are the most energy-efficient 4.0-kW class air conditioners that are available today, as of March 2008. Compared to air conditioners of 11 years ago, the X-series models consume about 40% less power per year than the earlier models.

CONCLUSIONS

This paper has highlighted some of the energy-saving technologies that we have incorporated in our refrigerators and room air conditioners. It goes without saying that these kinds of energy-saving technologies have not just been confined to these two appliances, but have been adopted across the board in virtually every kind of home appliance that Hitachi makes including washing machines, microwave ovens, rice cookers, and heat pump water heaters. Washing machines use considerable water, and because saving water helps reduce CO_2 emissions, we have made excellent progress improving detergency while at the same time reducing the amount of water used.

There is a tremendous expectation that making home appliances even more power thrifty and energy efficient holds the key to preventing global warming. And in order to promote widespread penetration of the energy-efficient home appliances, providing features and enticing benefits for users is indispensable. Hitachi Appliances, Inc. is committed to technological development contributing to further energy savings and prevention of global warming in the area of mature household appliance products.

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