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An Energy Saving Residential Cooling System with a Two Step Speed Compressor

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AN ENERGY SAVING RESIDENTIAL COOLING SYSTEM WITH A TWO STEP SPEED COMPRESSOR

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ABSTRACT

This paper describes an energy saving residential cooling system with a reciprocating compressor which can be operated at a two-step speed. The cooling system consists of one outdoor unit and three indoor ones, and they are controlled by micro-computers in order to save energy and to establish the best circumstances and ease of operation.

The compressor with a two-step speed system has a 2人-人winding motor, and it can supply a two-step capacity of 1 and 2 horsepower. The compressor is so designed that high motor efficiency and high lubrication quality can be obtained, especially when the compressor is operated at a low speed. The control system consists of a central control panel and branch control panels, which have micro-computers of 4 bit-single chip with 1 K or 2 K byte ROM. The central control panel has a switching on-off system for each indoor unit, a system for setting and monitoring the room temperature, and a system for selecting the prior cooling space. Each branch control panel has a switching on-off system for the indoor unit and a system for adjusting the room temperature and the fan speed of the indoor unit. In order to save energy and to establish the best circumstances, an algorism of the ROM which decides the amount of distribution of the refrigerant to the each indoor unit and decides the operating speed of the compressor, in accordance with the required cooling capacity of each area, was developed. It was concluded that the energy saving system presented in this paper was able to decrease the power consumption by 30 to 35%, compared with the conventional systems. This energy saving residential cooling system started to be manufactured in 1979, in Japan.

INTRODUCTION

To save energy in residential cooling appliances in order to alleviate the electrical peak load in summertime is very important problem due to the present energy crisis. This paper describes the details of a residential cooling system with micro computer which can save energy with great efficiency and can establish the best circumstances and ease of operation. This new system has the advantages both of a residential cooling system with a single indoor unit and a central type system. The main feature of this system is that it has a two-step speed compressor and it is carefully controlled by micro computers.

CONTROL SYSTEM

System Formation

Fig.1 shows a general view of the cooling system. The cooling system consists of one outdoor and three indoor units which are connected by refrigerating piping. Each indoor unit has a branch control panel. The system has a central control panel. The central control panel and the branch control panels have an intercom system.

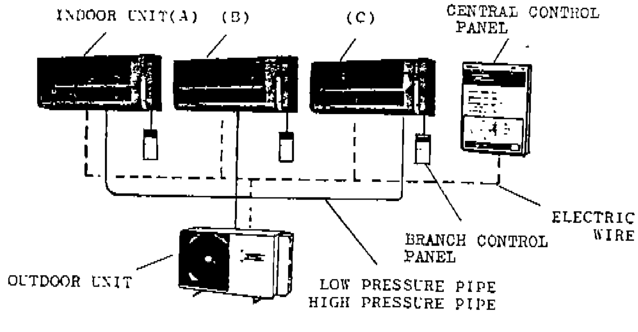


Fig.1 General view of cooling system

Outdoor Unit and Indoor Units

Fig.2 shows the block diagram formation of the cooling system. Each indoor unit consists of an evaporator with a capacity equivalent to about 1 horsepower, a ventilator and an expansion valve. The outdoor unit consists of a condenser with a capacity equivalent to about 2 horsepower; a two-step speed compressor which supplies 1 horsepower during the 4-pole operation and 2 horsepower during the 2-pole operation, and a ventilator. Since more than a certain amount of refrigerant in the cooling system has bad influence on the compressor, the inside diameter of the copper piping in the heat exchangers and volume of the receiver tank were designed as small as possible. In order to minimize the amount of the charged refrigerant. The maximum length possible of the piping which connects the outdoor unit to each indoor unit is 15m and the total maximum length possible of the piping which connects the outdoor unit to the three indoor units is 30m. The major specifications of the cooling system are shown in Tab.1.

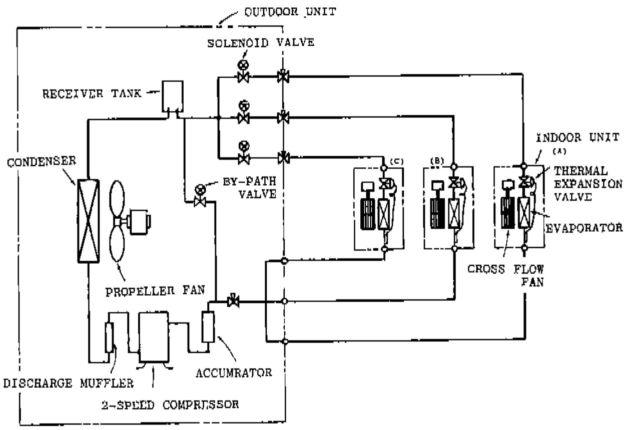


Fig.2 Block diagram formation of cooling system

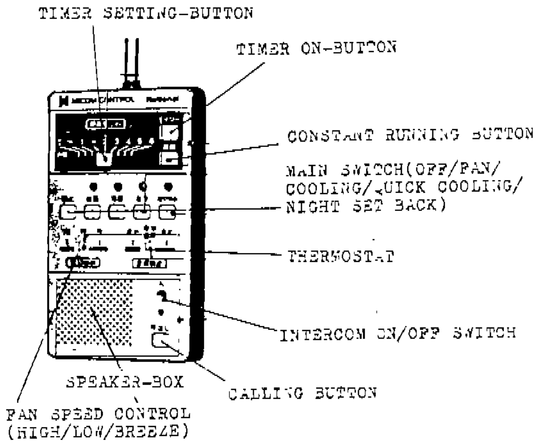
Branch Control Panel and Central Control Panel

Fig.3(a) shows the general view of a branch control panel which is connected to each indoor unit. The branch control panel has the following functions: (1)a main switch which can switch on and off the indoor unit independently of the central control panel. (2)a fan speed control which can adjust the speed in three ways, that is "High", "Low" and "Breeze". (3)a thermostat which can control the space temperature which is set by the central control panel, in the range of +1.5°C to -1.5°C. The longest time which the timer can be set for switching off, is 6 hours. The branch control panel has a night set back button.

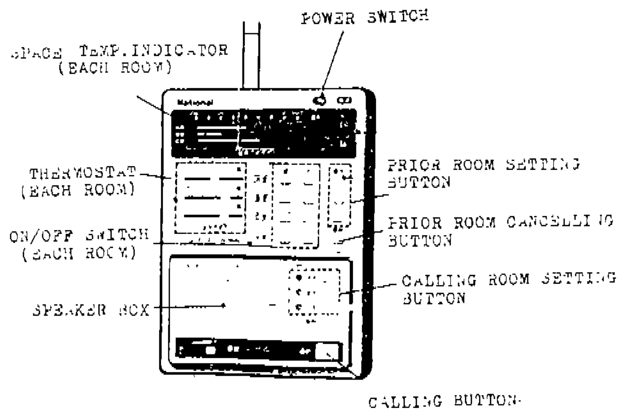
60Hz, 3phase, 200V, Comp.Output 750/1500W

		1-Room	2-Room	3-Room
Cooling Capacity (Btu/h)	4P	9770	5920x2	4490x3
	2P	—	9210x2	7030x3
Input (W)	4P	1140	1220	1310
	2P	—	2440	2670
EER (Btu/hW)	4P	8.57	9.7	10.3
	2P	—	7.55	7.9
Noise(dB(A)) Indoor Hi/Lo		43/27		
Outdoor Hi/Lo		53/48		
Net Weight(kg) Indoor		14 x 3		
Outdoor		87		
Dimensions(mm) Indoor		H340 x W760 x D190		
Outdoor		H535 x W930 x D410		

Tab.1 Specifications of the cooling system



(a) Branch control panel



(b) Central control panel

Fig.3 General view of control panels

Fig.3(b) shows the general view of the central control panel. The central control panel has the following functions: (1)ON/OFF switch which can switch on and off each indoor unit independently of the branch control panel. (2)a space temperature indicator which has LED, which can indicate the space temperature of each room, within the range of 23°C to 31°C by 1°C steps. But when the indoor unit is not in operation, the space temperature of the room is not indicated. (3)thermostats switch can set the space temperature of each room. (4)prior room setting buttons which work when the three indoor units are operated at the same time. As one of the prior room setting button is pushed, one corresponding space is more effectively air-conditioned.

TWO CYLINDER RECIPROCATING COMPRESSOR

Fig.4 shows the general view of a two-step speed compressor which is set in the cooling system. The major specifications of the compressor are shown in Tab.2. The outline of the compressor and the points which were given special attention when the compressor was designed, are as follows:

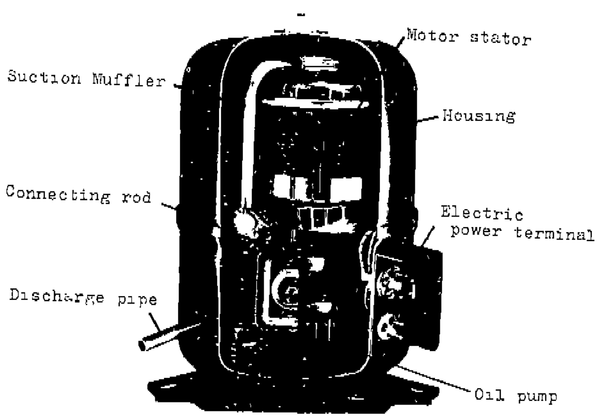


Fig.4 General view of a two-step speed compressor

Compressor Motor

The pole changing induction motors for the three phase have several windings. The induction motor of the compressor has a 2-pole 2⅄ and a 4-pole ⅄ winding, as shown in Fig.5. This winding was adopted, since the motor efficiency during the 4-pole operation is high. Even though motor torque during the 4-pole operation is smaller than that during the 2-pole operation, the cooling system is so designed that it can be operated in a small torque during 4-pole operation. Fig.6 shows the efficiency curves of the motor. The motor length is about 20 % long, compared with that of a single-speed compressor.

Specification of motor	
phase	3 ph
pole	2P/4P
output	750/1500 W
voltage	200 V
frequency	50/60 Hz
Mechanical constants	
bore	37.2mm
stroke	18.6mm
cylinder	2
displacement	40.3 cc/rev.

Tab.2 Specifications and dimensions of the compressor

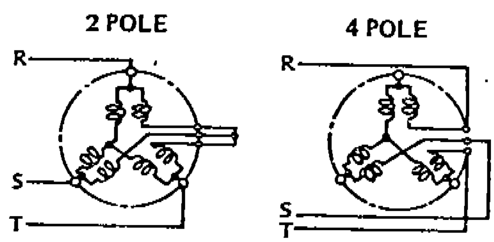


Fig.5 Winding of compressor motor

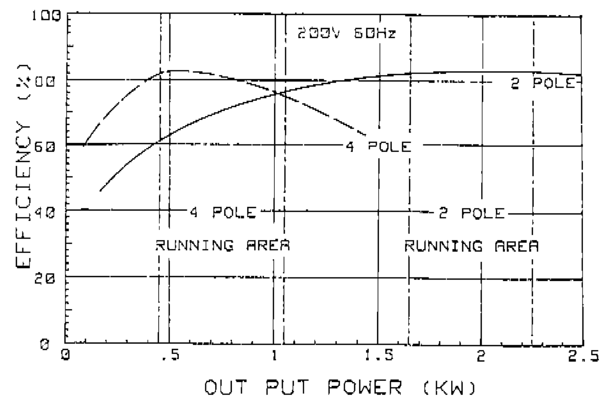


Fig.6 Motor efficiency

Design of Oil Pump and Discharge Piping

The oil pump of the compressor is of a centrifugal type. The oil pump capacity is greatly influenced by the rotating speed and the head is in proportion to the second power of the rotating speed. Hence, the head during the 4-pole operation is one fourth of that during the 2-pole operation. In the two-step speed compressor, careful consideration of this matter is necessary. The oil pump of the compressor is so designed that each pair of the piston-crank mechanism is sufficiently lubricated when the compressor is operated at the 4-pole.

The resonance vibrations of the discharge piping are one of the problems in the two-step speed compressor. When the 2-pole operation changes, to the 4-pole operation, the rotating speed of the crank shaft decreases and it becomes one second less of the rotating speed during the 2-pole operation. Hence, the discharge piping is so designed that the natural frequency of the piping does not agree with the rotating speeds during the 2 and the 4-pole operation and their harmonics.

Characteristics of Compressor

Fig.7 shows the performance curves of the two-step speed compressor. This figure shows that the EER during the 4-pole operation is higher than that during the 2-pole operation when the load for the compressor is small, and the EER during the 2-pole operation is higher than that during the 4-pole operation when the load is large. The 4-pole running area and the 2-pole running area in which the two-step speed compressor is actually operated, are shown in Fig.7. In conclusion, The SEER becomes higher when the ratio that the compressor is operated during the 4-pole operation increases.

Noises

Tab.3 shows the noise level of the compressor. The compressor noise level during 4-pole operation is considerably lower than that during the 2-pole operation. Hence, the compressor can be operated at a low noise level, when the load for the compressor is small as during the night.

Protection

In operating the two-step speed compressor it is necessary to prevent an overload of the compressor and the over current of the pole changing system which consists of four relays. Fig.8 shows the motor torque and the current curves during the 4-pole operation. As the 2-pole operation is changed to the 4-pole operation, the motor torque for the 2-pole operation rapidly changes to the reverse torque for the 4-pole operation, as seen in Fig.8. Hence, a violent impulsive force and a large electric current arises, and they may cause a damage of the relays and the compressor elements. In order to prevent this damage, the pole has to be changed from the 2-pole to the 4-pole, when the rotating speed has decreased sufficiently. Therefore, the timing of the switching on and off of the pole changing relays is very important. This timing is controlled by micro computers in the cooling system.

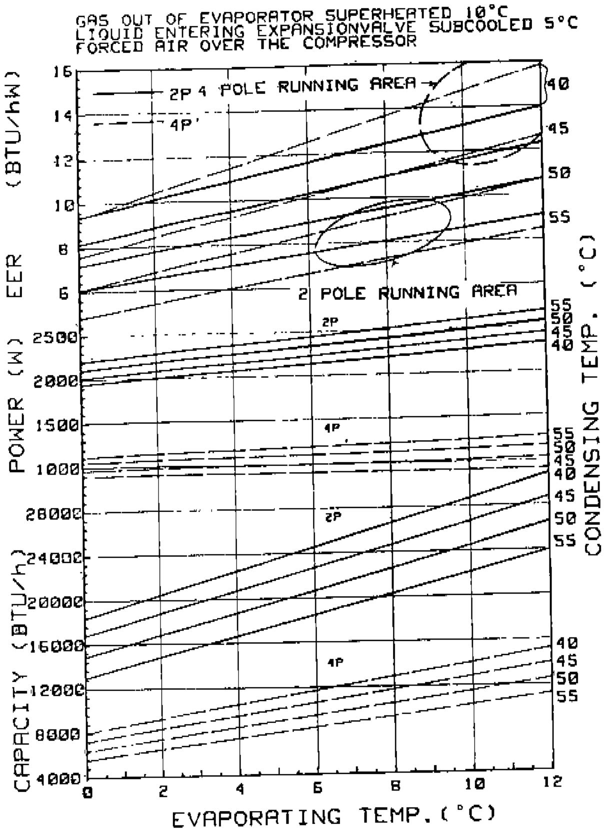


Fig.7 Performance curves for the two-step speed compressor

Operating condition		Noise dB(A)
2 pole	50Hz	69
	60Hz	69
4 pole	50Hz	59
	60Hz	62

Compressor only
Measuring distance : 30 cm

Tab.3 Noise level of the compressor

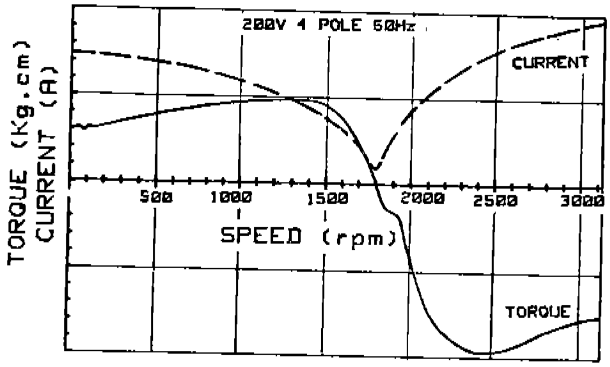


Fig.8 Torque and current cuvres of the 4-pole motor

THE CONTROL SYSTEM AND ALGORITHM

Generally in conventional air-conditioners, the cooling capacity of the air-conditioners is determined, on the basis of the maximum cooling load of the space. In such a multi-space cooling system as the cooling system in this study, the capacity of the outdoor unit which consists of the compressor and the condenser can be described as comparatively small. The reasons are as follows: when the maximum cooling load of three each space is 1 horsepower, the three spaces are respectively equipped with an indoor unit of which the capacity is 1 horsepower. Principally, the capacity of the outdoor unit should be 3 horsepower when the three spaces are under the maximum cooling load respectively. However, since it is seldom that the three spaces require the maximum cooling capacity at the same time, the capacity of the outdoor unit can be, in the case of this system, 2 horsepower, which is lower than the total horsepower of the three indoor units. Hence, in most case the outdoor unit can be equipped with a comparatively small capacity compressor, and the power consumption can be reduced.

Moreover, in the case of a system which has widely changing total cooling load, by controlling the compressor capacity in accordance with the total cooling load, the power consumption can be reduced further more. In order to practically apply the above system which makes it possible to reduce the power consumption, it is necessary to develop a new control logic which controls the compressor capacity and the amount of distribution of the refrigerant to each indoor unit, and which establishes the best circumstances of each room and ease of operation. In this section, the details of the new control logic are described.

Detection of air conditioning State and Algorithm Determining Operation Modes

In order to determine the operation modes of the compressor and the valves, the following three items of information have to be considered.

(1) The number of the cooling indoor units. The number of the cooling indoor units of which the main switch should be on and the thermostat should not be switched off.

(2) The air-conditioning state. As the deviation of the space temperature and the temperature which is set by users is considered one of the typical indexes of comfort, as show in Fig.9, the air-conditioning state is divided into four ranges which define the degree of comfort. Tri is the space temperature and Tsi is the temperature which is set by users. Range (I) shows an insufficient cooling state. ($Tri \geqq Tsi + 2°C$). Range (II) shows a slightly insufficient cooling state. ($Tsi + 2°C > Tri \geqq Tsi + 1°C$). Range (III) shows a comfortable cooling state. ($Tsi + 1°C > Tri \geqq Tsi$). Range (IV) shows an excessive cooling state. ($Tsi > Tri$).

(3) The balance of the cooling capacity and the cooling load. The temperature gradient $\Delta Ti/\Delta t$ is the index which shows a deficiency or an excess of cooling capacity against cooling load. As shown in Fig.10. (1) The capacity is smaller than the cooling load when $\Delta Ti/\Delta t > 0$. (2) The capacity is equal to the cooling load when $\Delta Ti/\Delta t = 0$. (3) The capacity is larger than the cooling load when $\Delta Ti/\Delta t < 0$.

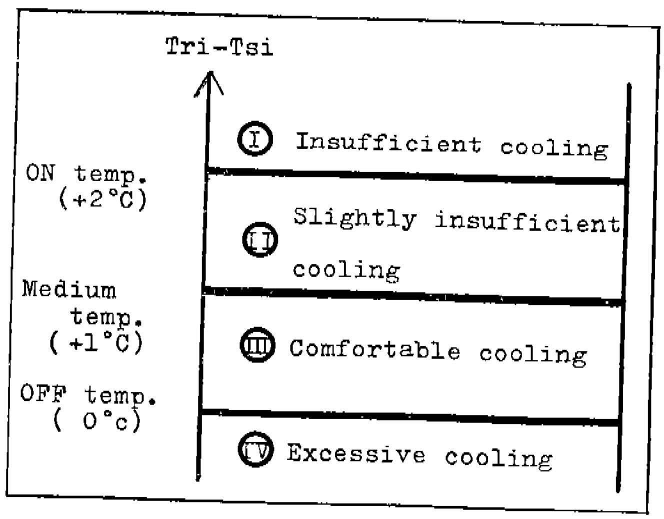


Fig.9 Detection diagram of the air-conditioning state

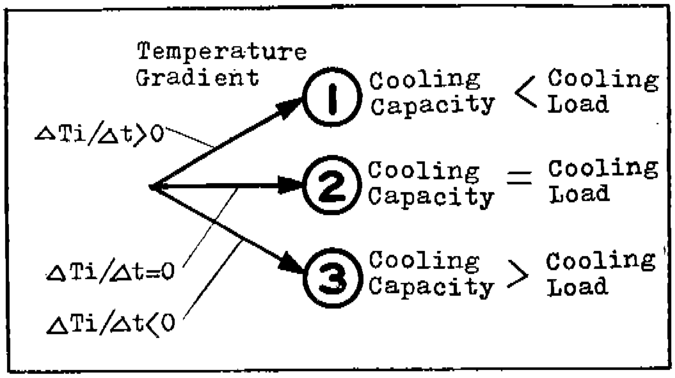


Fig.10 Detection diagram of the balance of the cooling capacity and the cooling load.

The information given in (2) and (3) make the following findings possible: as shown Fig.11 Ⓐ, Ⓑ, Ⓒ and Ⓓ which are in the range of Ⓘ or Ⓘ and the temperature gradient is zero or positive are defined as Q_{NO} which shows a shortage of cooling capacity. And Ⓔ which is in the range of Ⓘ and the temperature gradient is negative is defined as V_{OK} which shows a comfortable cooling state and sufficient of cooling capacity.

The operation mode of the compressor and the valves is determined by the following algorithm. When only one indoor unit is operated, the compressor is operated at the 4-pole. When multi indoor units are operated, the flow chart shown in Fig.12 determines the following operation modes. When there are not Q_{NO}-spaces, the compressor is operated at the 4-pole. When Q_{NO}-spaces appear and V_{OK}-space exists, the distribution of the refrigerant to the indoor unit in the V_{OK}-space is stopped. (The valve is closed). As a result of this, the cooling capacity for the Q_{NO}-spaces increases without changing into 2-pole operation. On the other hand, when Q_{NO}-spaces appear and the V_{OK}-space does not exist, the compressor is changed into 2-pole operation. As the result of this, the cooling capacity for the Q_{NO}-spaces increases.

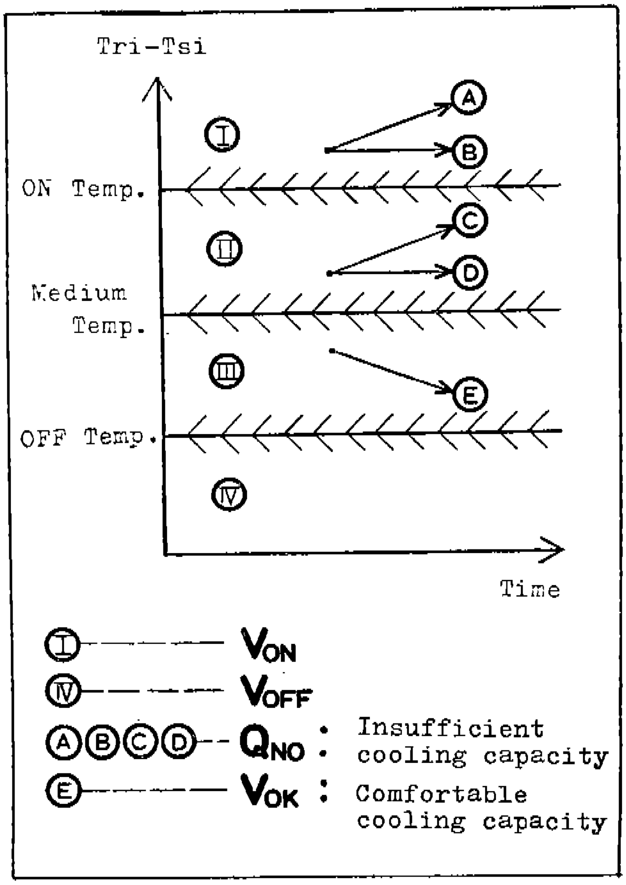


Fig.11 Information of determining the operation mode

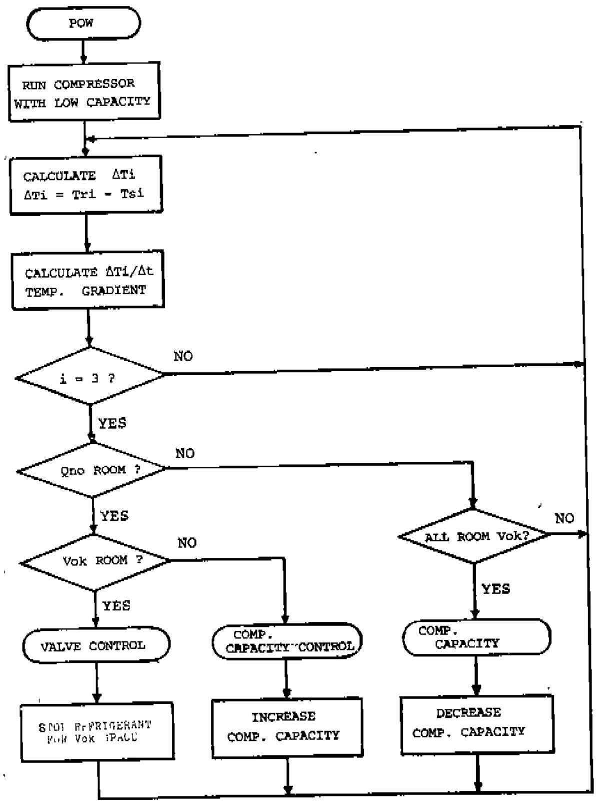


Fig.12 A main part of flow charts determining the operation mode

When the compressor is operated at 2-pole, every space becomes V_{OK}, then the compressor is changed into 4-pole operation again. In this algorithm, the time that the compressor is operated at the 4-pole is comparatively long, since the compressor is changed into the 2-pole operation only when the Q_{NO} spaces appear and there exists no V_{OK}-space. Hence, the SEER increases.

When an insufficient cooling state of Q_{NO}-spaces is not improving by the 2-pole operation, for example when every space is air-conditioned under high outdoor temperature, the following prior control system can be worked. When a user selects a prior air-conditioned space, the two spaces left are air-conditioned alternatively. Hence, the cooling capacity of the prior air-conditioned space increases.

Micro Computers

Fig.13 shows a block diagram formation of the control system which consists of multi micro computers. This control system is of a distributed type in which each micro computer processes a portion of the local and the whole work. The micro computers have the 1 K or 2 K byte ROM which is the 4-bit single-chip type. The analog signals of the space temperature is transmitted to the central control panel and theA/D converters convert them into digital data. The signals are interchanged between the micro computers, by a series of transmission systems, in order to minimize the lines between the units.

COMPUTER SIMULATION OF THE COOLING SYSTEM

The operation mode of the cooling system which was installed in a Japanese standard house was numerically simulated for the standard atomospheric conditions in summertime. Fig.14 shows the computer simulated results. In Tab.4 the computer simulated results of the new cooling system are compared with those of a conventional cooling system which has a single speed compressor of 2 horsepower. It is concluded that the new cooling system can reduce the power consumption greatly by 30 to 35 %, compared with the conventional one.

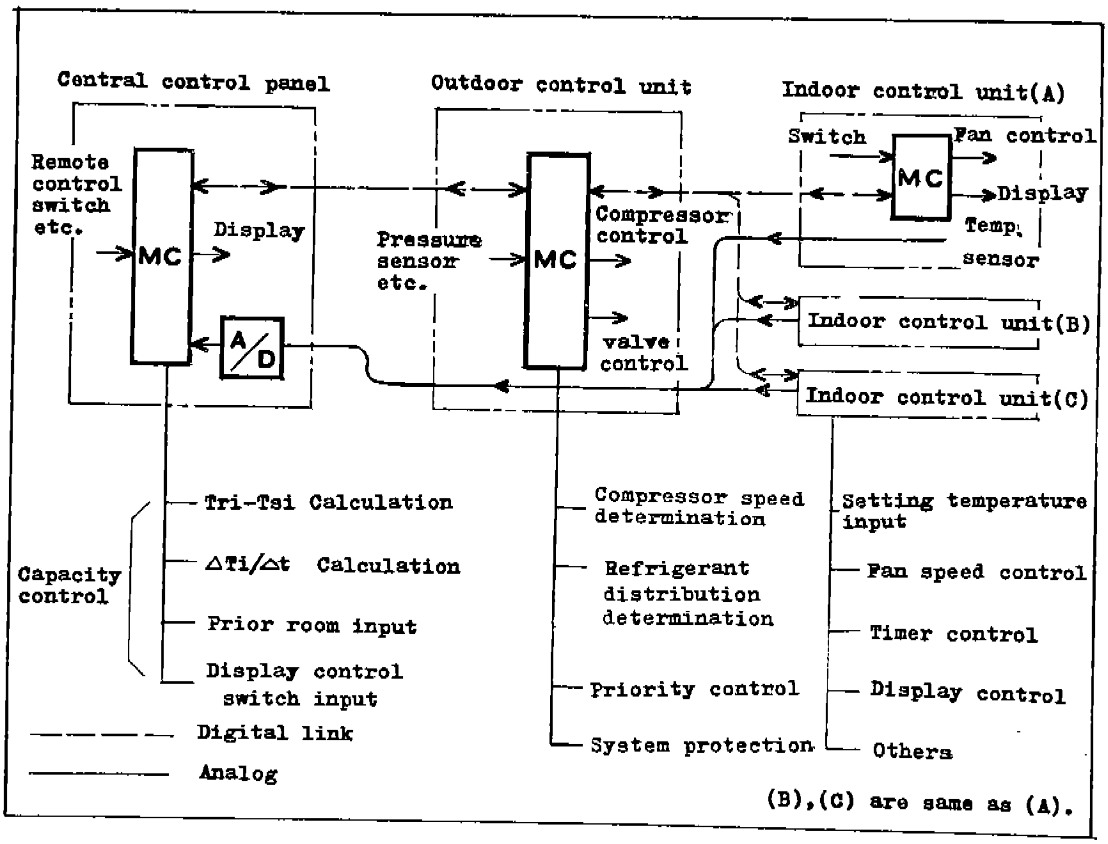


Fig.13 Block diagram formation of the control system

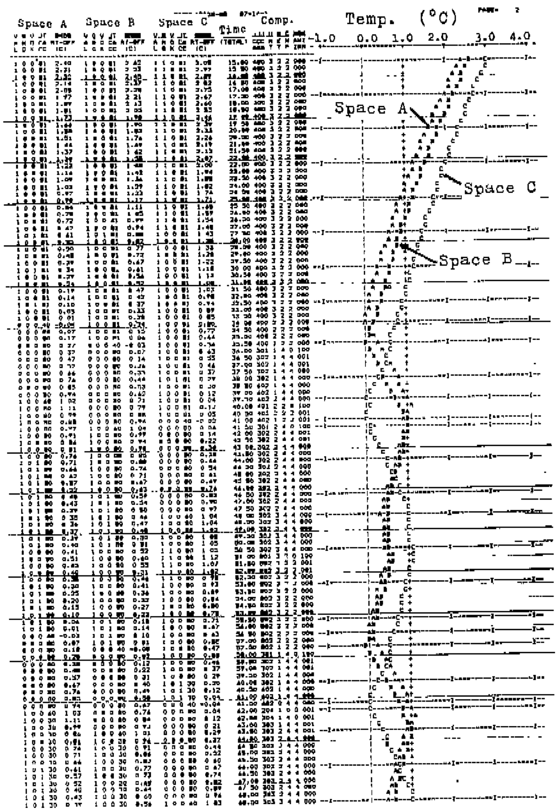


Fig.14 Computer simulated results

	Two Speed Comp. New Control	One Speed Comp. ON-OFF Control
Total Running Time (min.)	1440	1440
Comp. Running Time (min.)	685 (47.6%)	659 (45.8%)
2pole Running Time (min.)	196 (28.6%)	659 (100 %)
4pole Running Time (min.)	489 (71.4%)	
Total Input (kW)	15.325	24.825
Mean Capacity (Btu/h)	16756	17873
EER	12.48	7.91

Tab.4 Computer simulated results

CONCLUSION

In this study it was concluded that:

(1) Compared with the conventional cooling system, the power consumption for the compressor could be alleviated by 30-35 % by installing a 2 and 4 pole compressor in the cooling system which consisted of one condensing unit and three indoor units.

(2) In order to alleviate the shortage of electric power supply by installing two-step speed compressor in the cooling system and in order to establish the best circumstances and ease of operation, new softwares for system control have to be developed. This study has presented one of the new softwares.

The cooling system presented in this study started to be manufactered in 1979, in Japan.