Investigation and Analysis of Energy Consumption and Cost of Electric Air Conditioning Systems in Civil Buildings in Changsha

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Abstract: We investigated 40 typical air conditioned buildings in Changsha in 2005, including 15 hotel buildings, 6 commercial buildings, 5 office buildings, 6 hospital buildings and 8 synthesis buildings. On this basis we analyze the relation between types of cold and heat sources and the HVAC area of the buildings. Meanwhile the economical and feasible types of cold and heat sources are pointed out, i.e., oil boilers and gas boilers for heat source, and centrifugal and screw water chillers for cold source based on the electric refrigeration. Among the heat sources, the prospect of gas boilers is better. In addition, the air source heat pump depends heavily on whether some crucial issues such as frost can be solved during its application. The water-source heat pump will likely be applied. Based on the analysis of energy consumption and energy bills, we determine the feasible measures for energy conservation including the aspects of design, operation and management. Among them, special attention should be paid to energy metering and running time of air conditioning systems in civil buildings in Changsha.

Keywords: civil building; cold and heat source; energy bills; energy consumption; investigation

1. INTRODUCTION

At present, building consumes about 21%~24% of commercial energy in China, while heating, ventilation and air conditioning system (HVAC system) use more than 60% of the building energy consumption [1], thus, the selection of the cold and heat source and management of HVAC system are very important. In order to analyze the energy consumption and energy bills of HVAC system in Changsha, authors investigated 40 air conditioned buildings based on electric refrigeration in Changsha during the summer vacation in 2005. It includes 15 hotel buildings, 6 commercial buildings, 5 office buildings, 6 hospital buildings and 8 synthesis buildings(include office, hotel, commercial building and so on). The contents investigated include types of building, HVAC area, the type, capacity and number of the cold and heat source, yearly days for heating and cooling, whether or not adopting the technology of frequency conversion as well as energy consumption. Some basic information shows in Tab.1.

The purposes of this study are to discover the existing conditions of energy consumption and find out the economical and feasible types of cold and heat source along with the feasible energy-saving measures in Changsha. For these purposes, the following aspects are discussed. Firstly, we analyze the conditions of cold and heat source in these 40 buildings. Secondly, the energy consumption and energy bills in all kinds of building are compared and analyzed. Finally, some suggestions are given based on foregoing discussion.

2. ANALYSIS OF COLD AND HEAT SOURCES

2.1 Cold Source

In these 40 buildings, cold sources include screw water chiller, centrifugal water chillers, piston water chillers and air source heat pumps. Tab.1 shows that 16 buildings use screw water chillers (including 2 module chillers) and 18 buildings use centrifugal water chillers. These two types are the main cold sources, which accounts for 85% of the total investigated buildings. In addition, there are 6 buildings adopting air source heat pumps (including 1 module chillers) and 2 buildings adopting piston water chillers. There are two buildings adopting two types of cold sources at the same time. The module

Tab.1 Some basic information of every HVAC system in the 40 buildings investigated

Building name	cold source+ heat source	cooling load(w/m^2)		transducer	energy consumption[b]		bills (y/ m^2•d)[c]		
		design	running[a]	yes or no	fuel	electricity	cooling	heating	total
A-1	centrifugal+ oil boiler	105.5	79.1	no	1.27	0.27	0.23	0.5	0.33
A-2	centrifugal+ oil boiler	109	39.6	no	2.04	0.12	0.4	0.48	0.43
A-3	centrifugal+ oil boiler	127.3	63.6	no	1.58	0.42	0.35	0.71	0.52
A-4	centrifugal+ oil boiler	129.1	100	no	2.88	0.11	—	—	0.46
A-5	centrifugal+ oil boiler	150	108	no	2.82	2.17	—	—	1.32
A-6	centrifugal +coal boiler	120.3	90	no	6.42	0.36	0.32	0.35	0.34
A-7	centrifugal/piston+ electric boiler	140	45.9	no	none	0.11	—	—	0.09
A-8	screw+ oil boiler	163.6	57.5	no	0.63	0.74	—	—	0.45
A-9	screw+ oil boiler	70	39.6	no	—	0.39	—	—	0.3
A-10	screw+ oil boiler	116.3	100	no	1.23	0.48	—	—	0.45
A-11	screw+ oil boiler	174.5	82.9	no	0.6	0.1	—	—	0.13
A-12	screw+ gas boiler	139.2	110	no	—	—	0.18	—	—
A-13	screw+ electric boiler	63.5	50.8	no	none	0.09	—	—	0.09
A-14	piston+ district boiler room	139.6	93	no	—	—	0.31	0.13	0.23
A-15	module chiller+ gas boiler	80	75	no	—	—	—	—	0.36
B-1	centrifugal+ oil boiler	125	111.3	no	0.43	0.88	—	—	0.5
B-2	centrifugal+ oil boiler	110	65	no	1.29	0.24	0.13	0.44	0.23
B-3	centrifugal+ oil boiler	93.4	47	no	—	—	—	—	0.26
B-4	centrifugal+ electric boiler	120	100	no	none	1.38	—	—	0.73
B-5	centrifugal/heat pump+ electric boiler/heat pump	101	85.4	no	none	0.13	—	—	0.07
B-6	screw+ oil boiler	112.5	75	no	1.38	0.89	—	—	0.56
B-7	screw+ electric boiler	162.8	120	no	none	0.11	—	—	0.07
B-8	screw+ electric boiler	91.3	73	no	none	0.26	—	—	0.06
C-1	centrifugal+ oil boiler	67.9	45.2	yes	0.27	0.17	0.17	0.12	0.15
C-2	centrifugal+ oil boiler	150	99.7	no	0.29	0.11	0.09	0.14	0.11
C-3	centrifugal+ electric boiler	48.5	36.5	no	none	0.14	—	—	0.1
C-4	screw+ oil boiler	72	70	no	3.23	0.38	0.3	1.15	0.72
C-5	heat pump+ heat pump	189.7	110	no	none	0.74	—	—	0.37
D-1	centrifugal+ electric boiler	73	60	no	none	0.46	—	—	0.27
D-2	centrifugal+ —	175	63	yes	—	0.29	—	—	0.14
D-3	screw+ electric boiler	283.6	141.8	yes	none	2.22	1.05	2.24	1.64
D-4	heat pump+ heat pump	160	98	no	none	0.25	—	—	0.18
D-5	module heat pump+ module heat pump	140.8	105	yes	none	0.23	—	—	0.16
D-6	module heat pump+	60.4	50	yes	none	0.13	—	—	0.09

	module heat pump								
E-1	centrifugal+ oil boiler	150	96.7	no	0.18	0.2	—	—	0.22
E-2	screw+ gas boiler	87.9	36.8	no	—	0.29	0.25	0.66	0.41
E-3	screw+ electric boiler	278	111.7	no	none	1.11	—	none	0.92
E-4	screw+ electric boiler	225	129.5	no	none	—	—	—	0.05
E-5	screw+ none	97	85	no	none	0.23	0.23	none	—
E-6	heat pump+ heat pump	211.6	176	no	none	—	—	—	0.13

[a]The maximum load, [b]The unit is KWh/ m^2•day, [c]It is abbreviation for yuan/ m^2•day

A- hotel building, B- synthesis building, C- office building, D- hospital building, E- commercial building

chiller is the hot topic in the domain of central air conditioning system recently, but there are only 3 buildings adopting this system.

From the above analysis, we can see that screw water chillers and centrifugal water chillers are the main cold sources based on electric refrigeration in Changsha, and their proportions are equivalent; air source heat pumps take a certain share, and the percent of piston water chillers is the least. The high occupancy percent of screw water chillers owes to their good performance and low noise, and they are more flexible when comparing with centrifugal water chillers. The centrifugal water chiller mainly applies to larger projects, and the piston water chillers applied are very limited. In the buildings investigated, there is only 1 building's air conditioning system uses energy storage system, and there are no soil-source and water-source pumps adopted. To a certain extent, it shows that the promotion and application of new technologies and new systems should be better in Changsha, and people should pay more attention to energy saving of building.

2.2 Interrelation of Cold Source Types and HVAC Area

Fig.1 shows the interrelation of cold source types and HVAC area. We can see that 64% of the buildings whose HVAC area is less than 10000m^2 use screw water chillers; among buildings of HVAC area from 10001~20000m^2, the application of each cold sources type is equivalent. It follows that the cold source in small buildings can be of many types, as most types of cold source include chillers with low capacity. Among buildings of HVAC area from 20001~40000m^2, screw and centrifugal water chillers are the main cold sources, and the former accounts for 37.5% while the latter 50%. Besides, with the increase of HVAC area, the share of centrifugal water chillers is also increasing. Among buildings of HVAC area from 40001~60000m^2, 66.7% of the buildings uses centrifugal water chillers, and buildings whose HVAC area is more than 60000m^2, all of them use centrifugal water chillers. From the investigation and above analysis, it can be concluded that the screw water chiller is the main cold source in medium-sized and small-sized buildings; the centrifugal water chiller is the main cold source in large-sized buildings; the air source heat pump mainly applies to medium-sized and small-sized buildings; the application of piston water chiller is limited, and it always works as a auxiliary cold source.

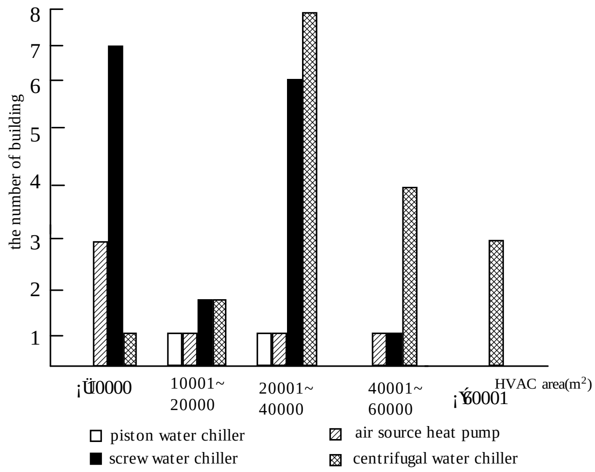

Fig.1 Interrelation of cold source types and HVAC area

2.3 Interrelation of Cold Source Types and Building Types

Fig.2 shows the interrelation of cold source types and buildings types. It can be seen that the screw and centrifugal water chillers are the main cold sources in hotel buildings (87.5% together), and the piston water chiller works as an auxiliary cold source. In synthesis buildings, the screw and centrifugal water chillers are also the main cold sources, and the proportion of the latter is more than the former. The centrifugal water chiller is the uppermost cold source in office buildings. The air source heat pump is mainly applied to hospital buildings, and the screw water chiller is the main cold source in commercial buildings.

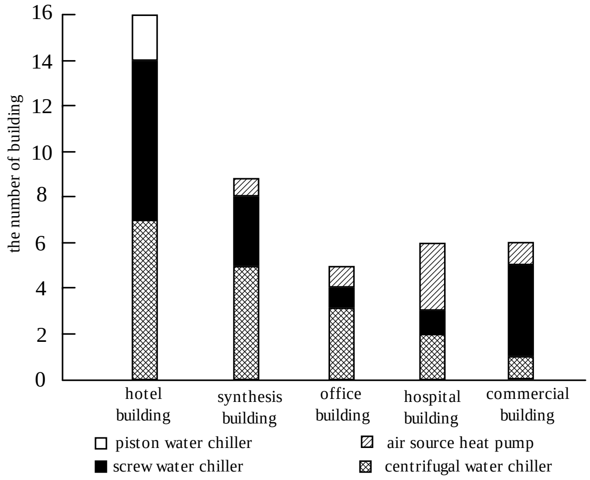

Fig.2 Interrelation of cold source types and building types

2.4 Heat Source

The types of heat source and their proportion are showed in Fig.3. The heat source types include district boiler room, dispersive boiler room and air source heat pump in 40 buildings investigated. 82% of the buildings use dispersive boiler rooms. There is only 1 building adopting district boiler room. Because Changsha locates the south of ChangJiang River, there is no heat supply network in city. The air source heat pump can not only supply cooling but also heating. So these buildings needn't have to set boiler rooms for heating.

2.5 Interrelation of Heat Source Types and Building Types

The application of various heat sources in the 40 buildings is showed Fig.4. It indicates that there are 14 buildings adopting dispersive boiler room among the 15 hotel buildings, and the other one adopts district boiler room. The air source heat pump and dispersive boiler room are both adopted in other kinds of building, and the dispersive boiler room is

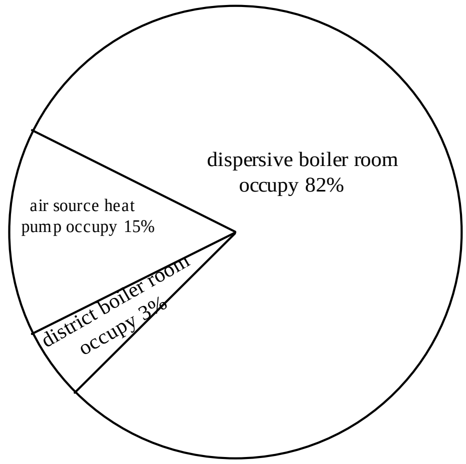

Fig.3 The types of heat source and their proportion

the main type. From the Fig.4, we can also conclude that the air source heat pump is applied to all kinds of buildings except hotel buildings, and it is mainly applied to hospital buildings. The dispersive boiler room is most popular, and there is only 1 building using district boiler room for heating.

3. ANALYSIS OF ENERGY CONSUMPTION AND ENERGY BILLS

In the 40 buildings investigated, the application of cold and heat sources is as follows: centrifugal water chiller +oil boiler for 11 buildings, screw water chiller +oil boiler for 6 buildings, air source heat pump for 6 buildings, screw water chiller +gas boiler

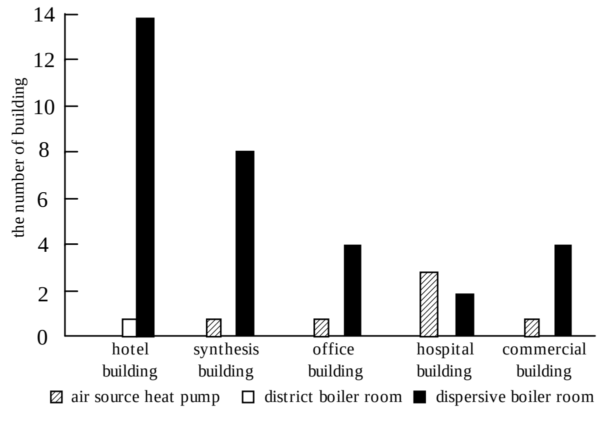

Fig.4 The application condition of various heat sources

for 3 buildings, coal-fired boiler for 1 building, electric boiler for 12 buildings (building E-3 never used), and no heat source for 1 building.

3.1 Characteristic in Hotel Building

Centrifugal water chiller +oil boiler, screw water chiller +oil boiler and screw water chiller +gas boiler are the main cold and heat source in hotel buildings. From Tab.1, we know that the fuel consumption on one square meter per day of the first and second cold and heat source is 1.27~2.88 KWh/m^2·d, 0.6~1.23 KWh/m^2·d respectively. Their electricity consumption are 0.11~0.42 KWh/m^2·d, 0.1~0.74 KWh/m^2·d respectively. The first one consumes 2 times as much as the second one, as they have the same heat source, so the reason for the difference is that it depends on the volume of hot water they supply and their energy management. The electricity consumption of centrifugal water chiller is more than screw water chiller, because it relates to the matching of water chiller and HVAC area and the performance of the chillers when it runs partly. The energy bills of the 3 cold and heat sources are 0.33~0.52y/m^2·d, 0.13~0.45y/m^2·d,0.36y/m^2·d respectively. The margin of the average bill of every cold and heat source is narrow in hotel buildings, and the average bill is about 0.4y/m^2·d. Some energy bills are much higher or lower than the average bill. On the one hand, different hotels may supply the different volumes of hot water. On the other hand, it also indicates that the potential of energy-saving is still considerable in hotel buildings. There is a lack of electricity bill in building A-5, so it is excluded in this analysis. From the above analysis, we can conclude that the measure of decreasing the fuel consumption is mainly to enhance the energy metering, and the measure of decreasing the unit's electricity bill is mainly to select suitable chillers according to the cooling load and the characteristic of fractional load.

3.2 Characteristic in Synthesis Building

Screw and centrifugal water chillers are the main cold sources in synthesis buildings, and oil boilers and electric boilers are the main heat sources. Seen from Tab.1, the margin of the average energy consumption and energy bill of every cold and heat source in synthesis buildings is considerably large. The maximum energy consumption is 1.38 KWh/m^2·d and the minimum is 0.43 KWh/m^2·d. The maximum electricity consumption is 1.38 KWh/m^2·d and the minimum is 0.11 KWh/m^2·d. They cost 0.73 y/ m^2·d for the highest bills and 0.06 y/ m^2·d for the lowest bills. The energy bills of some buildings with electric boiler are low than that of others. It can be concluded that the potential of energy-saving is considerable in synthesis buildings. For this kind of building, the energy-saving measures are mainly to enhance energy metering and analyze the energy cost reasonably.

3.3 Characteristic in Office Building

The main cold sources of office buildings are screw water chillers, centrifugal water chillers and air source heat pumps, and the main heat sources are oil boilers, electric boilers and air source heat pumps. Oil boiler's energy consumption is 0.28 KWh/m^2·d. Building C-4 is an exception, and its consumption is 3.23 KWh/m^2·d which is much higher than 0.28 KWh/m^2·d for the reason that it supplies hot water. To the electricity consumption, the bill of air source heat pumps is highest for 0.74 KWh/m^2·d, and the following is screw water chiller for 0.38 KWh/m^2·d, and the bill of centrifugal water chillers is lowest for 0.15 KWh/m^2·d. To the energy bills, the bill of buildings with air source heat pump is highest for 0.37 y/ m^2·d, and the value of bills in other buildings is about 0.12 y/ m^2·d. From the above analysis, it is known that the energy bill of air source heat pumps is highest, and the energy bill of oil boilers is equivalent to that of electric boilers. It indicates that enhancing energy metering and analyzing the energy cost reasonably are also the main energy-saving measures to the office building.

3.4 Characteristic in Hospital Building

The main cold sources of hospital buildings are screw water chillers, centrifugal water chillers and air source heat pumps(including module chillers), and the heat sources are mainly the electric boiler and air source heat pump. Seen from Tab.1, the electricity consumption of buildings with electric boilers is the highest about 0.46~2.22 KWh/m^2·d, and air source heat pumps' is lower about 0.25 KWh/m^2·d, and the module air source heat pump's is lowest. The energy bills and electricity consumption per square meter per day changes at the same time because electricity is the only energy consumption in cold and heat sources of these buildings. The above analysis indicates that the electric boiler is not very fit for heating. The module air source heat pump is in favor of energy-saving than that of ordinary type. Adopting oil boilers and gas boilers instead of electric boilers is the main energy-saving measure in hospital building. In addition, enhancing energy metering and analyzing the energy cost reasonably are also important.

3.5 Characteristic in Commercial Building

The main cold source of commercial buildings is the screw water chiller, and the main heat source is the electric boiler. Tab.1 indicates that energy consumption of commercial buildings is mainly for cooling. Because the heating period of most commercial buildings is comparatively short, and heating is even not necessary to some commercial buildings. That is why the energy bills are scarcely affected by electric boilers. From the above analysis, it can be concluded that reducing the runtime of water chillers is the foremost way for energy-saving to commercial building. The indoor thermal environment can be improved by ventilation when water chillers are not working.

4. ECONOMICAL AND FEASIBLE HEAT SOURCES AND COLD SOURCES BASED ON ELECTRIC REFRIGERATION

4.1 Heat Sources

The oil boiler is the most important heat source in the 40 buildings investigated. In this investigation, the heat sources with heating bills from high to low are electric boilers, gas boilers, oil boilers, coal-fired boilers and the district boiler room respectively. It illuminates that the coal-fired boiler is more economical than the oil boiler and gas boiler for heating. And the district boiler room is the most economical one. But it’s not so promising to be applied in the south of China. The environment will be polluted by the coal-fired boiler, so it is not an option. The electric boiler is the most uneconomical, and their bills are maximum one. For it can not profitably use the energy for heating. So the electric boiler is not a fit heat source for most of buildings except some especial buildings such as hospital. With the development of economy and the shortage of oil, oil boiler faces some competition pressure. Now, the natural gas has been transported to Changsha, so the gas boiler as a heat source is comparatively promising. In this way, the gas boiler is not only economical, but it can also optimize our country’s energy structure.

From the above analysis, the economical and feasible heat sources are the oil boiler and gas boiler in Changsha, and the gas boiler is the more promising one correspondingly.

4.2 Cold Sources Based Electric Refrigeration

Centrifugal water chillers, screw water chillers and air source heat pumps are more prevalent than other cold sources in the 40 buildings investigated. Changsha is a well-known “furnace” in summer. High ambient temperature will turn the performance of air source heat pumps from bad to worse. Another problem is that the evaporator of air source heat pump will frost in the moist air during winter. Changsha locates in the Changjiang valley where it is very hot in summer and wet in winter. So the air source heat pump is not a perfect cold source in Changsha unless its performance is improved by a long way. We should pay more attention to that the water source heat pump is a good cold source in the Changjiang valley where is abundant in water, although none WSHP among our investigation. The performance of water source heat pumps is hardly affected by the temperature and humidity of surroundings. So the water source heat pump will be an economical and feasible cold source in Changsha in the further.

From the above analysis, the economical and feasible cold sources are mainly the centrifugal water chiller and screw water chiller, and the air source heat pump is restricted by some technical problems. The water source pump is worthy of being attempted to apply in Changsha in the further.

5. FEASIBLE ENERGY SAVING MEASURES IN CHANGSHA

The energy consumption of large-sized public buildings is mainly all-year electricity, and HVAC system consumes 40%~60% of it[2]. Comparing with energy bills in Changsha, the average electricity bill for air conditioning in large-sized public buildings in Beijing is about 0.56KWh/m^2·d(135 days for cooling)[2]. In Beijing, the electricity bills for air conditioning is about 0.49KWh/m^2·d in hotel building, about 0.45KWh/m^2·d in office building and about 0.8KWh/m^2·d (180 days for cooling) in commercial building[2~3]. From the above analysis, it can be concluded that the energy bills of Changsha and Beijing are different; and the proportion of energy-saving in large-sized public buildings can attain to 30%~50% in Beijing[2], so there is also some potential of energy-saving in some scopes in Changsha..

Some shortcoming of design, usage and management are exposed by analyzing the use of HVAC systems in the 40 buildings investigated, and all these lead to waste much energy. Accordingly, some feasible energy-saving measures are suggested as follows.

5.1 Design

1) Selecting a economical and feasible cold and heat source which is in favor of optimizing energy structure

Considering the above analysis and actual situations in Changsha, the oil boiler and gas boiler can be selected as heat source, and the screw and centrifugal water chiller can be selected as cold source based on electric refrigeration. The water source heat pump can be also selected if it is technically feasible.

2) Degrading the design load index

Seen from Tab.1, the maximal running load deviates greatly from the design load in most buildings. It makes the chiller always running with a fractional load, and the efficiency of chiller is very low under this situation. So the matching of running load and design load is very important.

3) Adopting the control technology of frequency conversion for pumps and fans

Cooling and heating loads are uneven in a year, and the chiller always runs with a fractional load. Adopting the control technology of frequency conversion for pumps and fans is a very effective energy-saving method according to the change of load. But there are only 5 buildings adopting this technology in the 40 buildings investigated.

Considering energy-saving during design is one of the very effective ways, so it is very important to improve designers' consciousness of energy-saving.

5.2 Operation

1) Degrading the set standard of indoor temperature and humidity

In this investigation, we find the standards of temperature and humidity are setted overhigh in some buildings. For example, you will be rather chilly when standing in the hall of some hotel buildings. So selecting a fit and comfortable standard of temperature and humidity is very valuable.

2) Reducing the running time of cold and heat sources

Seen from Tab.2, the cold and heat sources run about 300 days together annually in most buildings, and some even over 300 days. Tab.2 shows the interrelation of the yearly running time of cold and heat sources and building types. It indicates that the yearly running time of cold source is 125~165 days

Tab.2 The number of days for cooling and heating in every kind of building

Days	Number of A		Number of B		Number of C		Number of D		Number of E	
	cool	heat	cool	heat	cool	heat	cool	heat	cool	heat
30~60	0	0	0	1	0	1	1	0	0	2
80~120	2	6	2	6	2	3	3	3	1	2
125~165	9	8	3	0	2	1	1	3	2	0
180~225	4	1	1	1	1	0	1	0	3	0
240~300	0	0	2	0	0	0	0	0	0	0

A- hotel building, B- synthesis building, C- office building, D- hospital building, E- commercial building

There are two commercial buildings whose heat sources are never working.

in most hotel buildings, synthesis buildings and office buildings. And hospital buildings and commercial buildings is 80~120 and 180~225 days respectively. For the yearly running time of heat source, 125~165days is for most hotel buildings and 80~120 days is for most synthesis buildings and office buildings. The yearly running time of heat source is no more than 120 days in all buildings investigated, and there are two commercial buildings which do not supply heating. Seen from Tab.2, in each type of building there are several buildings whose running time of cold and heat source deviates from the average days. To some extent, this shows energy consumption can be decreased by reducing the running time of cold and heat sources. Ventilation by opening windows is a very important energy-saving measure especially in transition season.

3) Choosing energy storage air conditioning systems

There is only 1 building (B-8) adopting ice bank systems. The energy storage system can not save energy, but it can reduce the running bills. At the same time, it can also balance the electrical network peak. Because the load of electrical networks is too high in Changsha in hot summer of last few years, the government has to cut the supply of electricity in some districts. So the energy storage system for cooling is recommendable.

5.3 Management

Enhancing the energy metering and analyzing the energy cost

We find that there are hardly any special ammeters and fuel gauges in all the buildings investigated. A single ammeter is usually applied to meter all kinds of electricity consumption such as lighting, air conditioning, heating and so on. It turns out that the governor don’t know the energy consumption respectively for air conditioning and heating clearly, so it induces the governors have little energy-saving consciousness. It is suggested that the energy consumption for cooling and heating should be metered respectively. In addition, the governor should analyze the energy cost monthly. In this way, we can find the solutions according to the metering data of each device. For the building with multi-user, the heating-cooling metering system is very necessary and important. It can supply energy according to demand.

6. CONCLUSION

In this paper, we find out the economical and feasible heat sources and cold sources based on electric refrigeration in Changsha by analyzing the energy consumption and energy bills in the 40 buildings investigated. Several energy saving measures are presented on design, operation and management. It is pointed out specially that enhancing the energy metering and reducing the runtime of cold and heat source are the most important approaches for energy saving in civil buildings in Changsha.

REFERENCES

[1] Jiang Yi. Current building energy consumption in China and effective energy efficiency measures (in Chinese). HV&AC, 2005, 35(5):31-40.

[2] Xue Zhifeng, Jiang Yi. Energy consumption and energy saving potential analysis for large-scale public buildings in Beijing(in Chinese). HV&AC, 2004, 34(9):8-10.

[3] Jiang Yi, Xue Zhifeng. Energy consumption status and energy conservation method analysis of buildings in Beijing(in Chinese). HV&AC, 2004, 34(10):13-16.