DEVELOPMENT OF A KILN DRIED WOOD SYSTEM USING HEAT PUMP TECHNOLOGY

Kimitaka KADOWAKI, Foreman, MAYEKAWA MFG.CO.,LTD. , 2000 Tatsuzawa, Moriya City, Ibaraki, 302-0118, Japan
Akito MACHIDA, Deputy Head, MAYEKAWA MFG.CO.,LTD. , 2000 Tatsuzawa, Moriya City, Ibaraki, 302-0118, Japan
Kousaku NISHIDA, Manager, MAYEKAWA MFG.CO.,LTD. , 2000 Tatsuzawa, Moriya City, Ibaraki, 302-0118, Japan
Masashi KATO, Foreman, MAYEKAWA MFG.CO.,LTD. , 2000 Tatsuzawa, Moriya City, Ibaraki, 302-0118, Japan
Yukitaka KATO, Associate Professor, Tokyo Institute of Technology, 2-12-1-N1-22, Ookayama, Meguro-ku, Tokyo, 152-8550, Japan
Shuetu SAITO, Chief of Laboratory, Forestry and Forest Products Research Institute, 1, Matsunosato, Tsukuba, Ibaraki, 305-8687, Japan

Abstract: The CO_2 heat pump has gained considerable attention because it is both environmentally friendly and highly efficient during high temperature heating. Because of the high efficiency during high temperature heating, the heat pump can be applied as drying equipment with humidity and temperature regulation functions.
In this research, we developed a kiln dried wood heat pump system with humidity and temperature regulation functions. This paper reports on the outline, performance and economics of the dehumidifier system.

Key Words: Heat pump, Drier, Natural refrigerant, Heating

1 INTRODUCTION

In recent years, global warming issues have become a serious social problem and calls for green house gas reductions have become prominent. In addition, soaring oil prices are now beginning to affect the Japanese economy. In such resource and environmental constraints, therefore, transition to a low carbon society that does not depend on fossil fuels is urgently called for. One of the alternatives is the promotion of renewable energy as a countermeasure. In particular, the heat pump is expected to contribute to about 30% or renewable energy by 2020. It is easily possible to extract hot air of 120℃ with a CO_2 heat pump. This was not previously possible with fluorocarbon heat pumps. Therefore, a CO_2 heat pump is expected to play a big part in providing high temperatures for industrial use.
And in the field of timber resources, increasing global demand for timber, momentum of resource nationalism, increasing of using woody energy, and prevention of global warming by material conversion to wood, and momentum for low carbon path.
And more, in the field of forestry in Japan, artificial forest resources planted after the war are already becoming utilizable. The Ministry of Agriculture, Forestry and Fisheries of Japan take this occasion to start to check up for activation of forest and forestry as “Forest and Forestry revitalization plan” from December 2009. And the target is to have over 50% self-sufficiency ratio of timber in 10 years after.
On the other hand, boilers using fossil fuels make up 80% of the wood drying market. The soaring fuel prices, therefore, directly affect the wood drying industry. Direct burning of fossil fuels also results in emissions of greenhouse gases. Fluorocarbon heat pumps were

previously introduced in the market. However, because of low dryer temperatures and humidity control problems, they were not widely used.
To over come the above problems, the Ministry of Agriculture, Forestry and Fisheries of Japan from 2008, sponsored the development of a highly efficient drying of high-quality wood using CO_2 heat pump technology.

2 OUTLINE OF THE SYSTEM

In order to produce high quality timber, precise temperature and humidity control is required. An air source and sink CO_2 heat pump can be used to regulate both humidity and temperature to provide the ideal air dehumidifier. However, there is a challenge to balance the sink load, the amount of heat required for drying wood the source load and the amount of dehumidification required. Figure 1 shows the heating and cooling load during the drying of cedar wood. The heating and cooling loads are different on the first and third day.

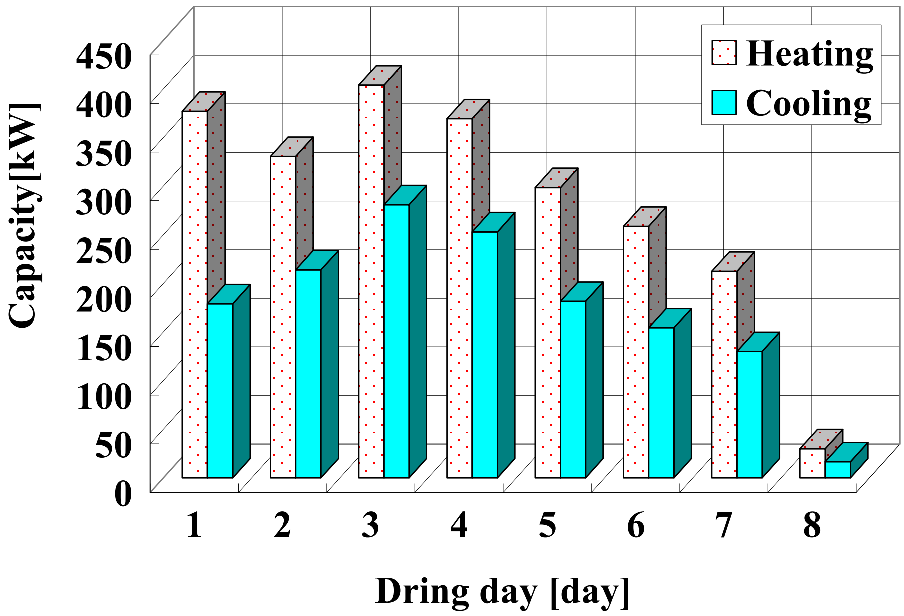

Fig.1 Time history of heating and cooling capacity

A market research of a Kiln dried wood systems showed that almost 70% of drying rooms have a space volume of 10 ～ 50m^3. With this information, development goals were set as follows.
In order to supply high temperatures CO_2 refrigerant is used.
Two air heat exchangers and one water heat exchanger are used to balance the sink and source loads.
The size of the Kiln was decided to be 23(m^3) from the capacity of the compressor and market research.
The Kiln humidity is adjusted by both source heat dehumidification and heat recovery –air dehumidifier.
Target timber is Cryptomeria and Japanese cypress used in the house construction industry.

The outline of the system is shown in Figure 2. The Kiln wood drier comprises of a heat pump side and the Kiln side. In order to balance the sink and source loads, an additional heat exchanger is provided above the gas cooler. The additional heat exchanger is used as a heat sink or heat source in order to balance the load.

2.1 Heat pump side

The heat pump side mainly consists of a compressor, evaporator, gas cooler, additional heat exchanger, expansion valve and refrigerant heat exchanger.

This system can use both air and water as heat source. In the air heat sink made, high temperature and pressure CO_2 refrigerant from the compressor exchanges heat with air in the gas cooler. The refrigerant is cooled while air is heated to about 100℃. CO_2 meanwhile, goes through the internal heat exchanger, expansion valve, additional heat exchanger and internal heat exchanger and then back to the compressor.

In the water heat source made, cold water is produced in the evaporator.

2.2 Kiln side

The Kiln side mainly consists of a dehumidifier, kiln, heat storage tank, fan, pump and damper.

High temperature air generated in the gas cooler is sent to the kiln where it dries wood. Air from the kiln is of low temperature and high humidity and goes to the dehumidifier. From the dehumidifier air is again sent to the gas cooler by a fan. To prevent uneven drying of wood, the direction of air flow in the kiln is interchanged every two hours.

2.3 Physical appearance of the heat pump system

Figure 3 shows the appearance of the CO_2 heat pump. The design pressure is 15MPa and the motor nominal power is 25kW. Figure 4 shows a sketch of the kiln.

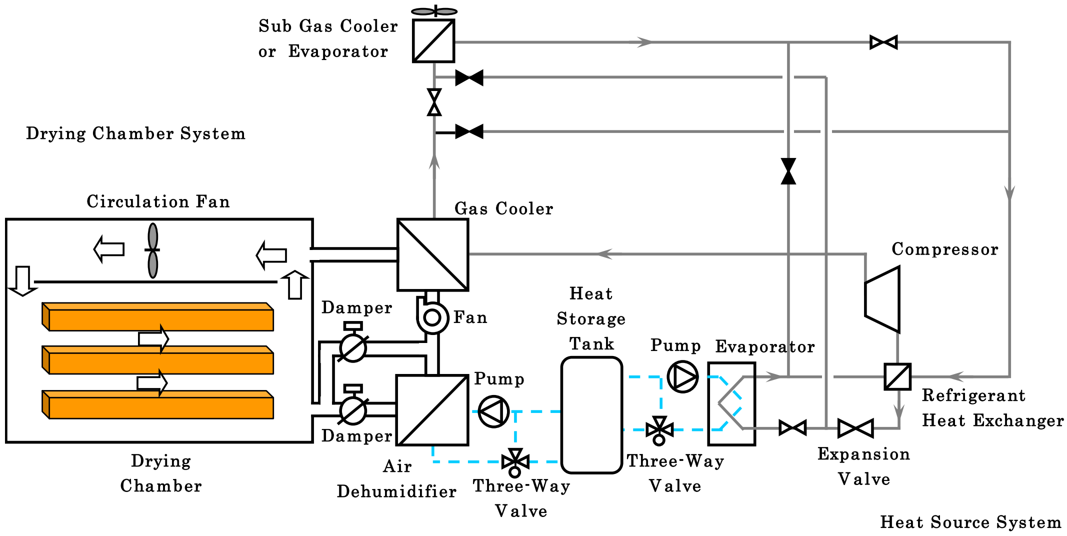

Fig.2 Schematic of a Kiln dried wood system

Fig.3 CO_2 heat pump unit

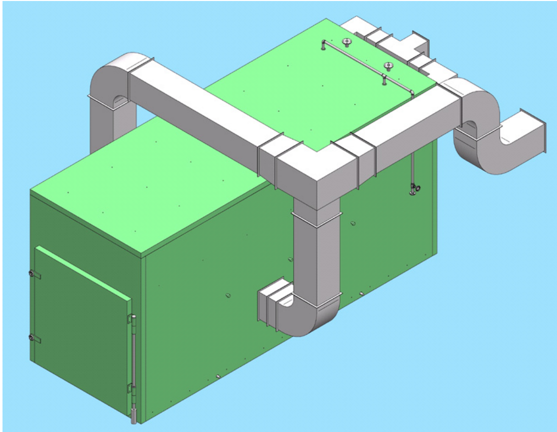

Fig.4 Kiln Drier

3 CONTROLS

In order to provide high quality and efficient wood drying in a short time, the system has three operating modes, the start-up, drying and defrost mode. The start-up mode raises the dry room temperature promptly and is air driven. The drying mode provides both temperature and humidity control through exhaust heat and air heat recovery mode to balance load within the Kiln. System flows for exhaust heat and air recovery mode are shown in figures 5 and 6 respectively.

The defrost mode is used during start up and recovery modes.

In drying mode, the Kiln temperature, humidity, and evaporated temperature controls are independent. High quality drying, high speed, or high efficiency drying mode depending of the type of wood dried one can select.

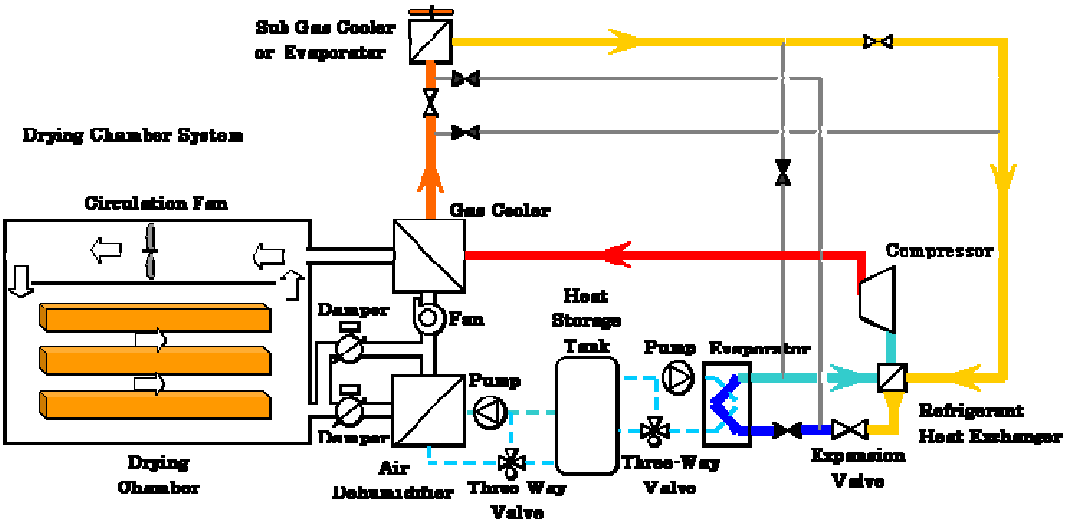

Fig.5 Exhaust heat recovery mode

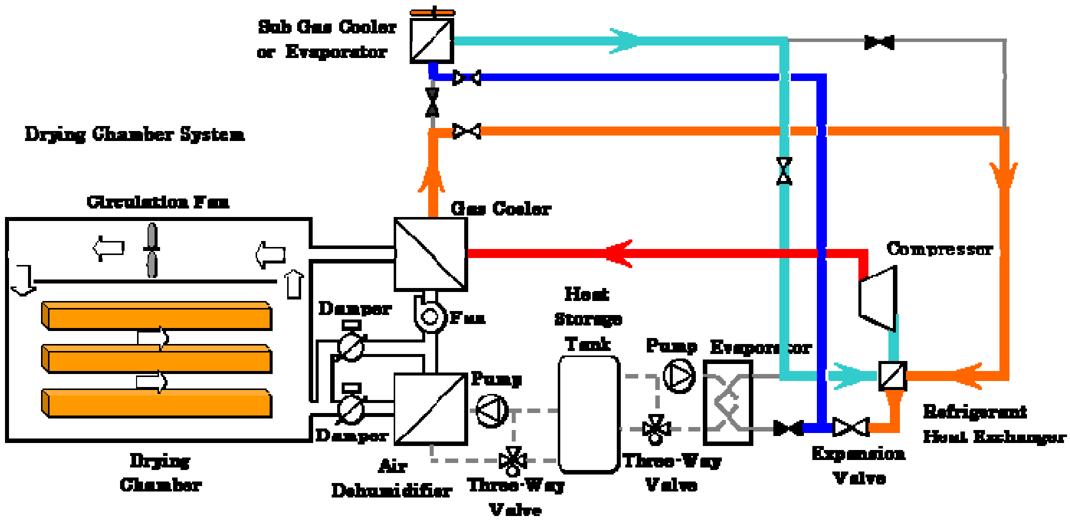

Fig.6 Air heat recovery mode

3.1 Condition control

3.1.1 Temperature control in the Kiln

The temperature in the Kiln is controlled by air temperature and air flow rate. The air temperature is controlled by both compressor rotation speed and discharge pressure.

3.1.2 Humidity control in the Kiln

Moisture control in the Kiln is adjusted by water temperature is the dehumidifier.

3.1.3 Evaporating temperature control on CO2 heat pump unit

Stability of the hot air temperature at the gas cooler exit depends on stable heat recovery in the evaporator. The evaporation temperature is therefore, controlled in order to balance the load.

3.2 Drying mode

3.2.1 High quality drying mode

Wood drying quality is a highly related to kiln humidity. Decrease humidity cause cracks and deformations in the wood. This system humidifies the kiln with water evaporation from the drying wood. Therefore, decrease in humidity during start up. Therefore, in high quality drying mode, other than temperature control, humidity control is given priority. Kiln temperature is controlled to keep the kiln humidity high. Wood drying is done without lowering the quality.

3.2.2 High speed drying mode

In high speed drying mode, temperature control is given priority to humidity control. It's the temperature rises, humidity lowers, thus drying speed increases.

3.2.3 High efficiency driven mode

This mode gives priority to the efficiency of the CO_2 heat pump system. The temperature between the gas cooler inlet and outlet air temperature is kept constant to optimise the heating capacity. This is done by control up the speed of gas cooler fan and gas cooler inlet and outlet air temperatures.

4 ECONOMICAL VALUATION

The environmental impact and CO_2 emissions were examined for different heat sources and the results are shown in table 1. The calculation conditions are, Cryptomeria board material with a volume of 45.5 m3, kiln temperatures 70～79℃, drying time 91 hours and operating 60 time per year. The CO_2 emission factor is 0.332kg- CO_2 /kWh for electricity and 2.49kg- CO_2 /L for kerosene. The Tokyo Electric Power costs are used while fuel costs are set at 65.5 yen/L. Water and used sewage bills Tokyo Metropolitan Government are used while the boiler efficiency is set at 90%.

Results show that using a CO_2 heat pump reduces CO_2 emissions by more than 67.8% compared to a kerosene fired boiler system while running costs are reduced by more than 50%.

Table.1 Comparison of CO_2 emissions and running costs

Drying system		CO2 heat pump system	Paraffin boiler system
Temperature of a Kiln	℃	70～79	70～79
Humidity of a Kiln	%	87～60	87～60
CO2 emissions	t-CO2/year	126.40	392.45
CO2 reduction ratio	%	67.8	-
Annual running costs	million yen/year	5.97	12.02
Annual reducation of cost	million yen/year	6.05	-

5 RESULTS AND DISCUSSION

Cryptomeria with a high water and Japanese cypress with high-value added board (35×134×1600mm, 480 pieces, with timber volume of 6.8m^3) was used. Drying tests were carried out according to the timber drying schedule. As well, high speed drying mode was used in Cryptomeria drying, and high quality drying mode was used in Japanese cypress drying.

5.1 Time history of temperature and humidity

Figure 7 shows time history of temperature and humidity in high speed drying mode (Cryptomeria board), and Figure 8 shows time history of temperature and humidity in high quality drying mode (Japanese cypress board). The drying schedule of Cryptomeria board is shown in Table 2 and the schedule for cypress board drying schedule is shown Table 3. The fluctuations in data are caused by interchanging of air flow within the kiln to prevent uneven drying of wood.

In Figure 7, the humidity in the dry room is 10% lower than the schedule humidity for the first 20 hours of operation. Though, in high speed drying mode, drying temperature control is takes priority to humidity control. As a result, drying temperature and schedule temperature correspond.

On the other hand, in Figure 8, during start up, the Kiln humidity is high while Kiln temperature is lower than scheduled one. The Kiln humidity reaches the target humidity after 20 hours. Wood drying quality highly depends on wood moisture and Kiln humidity. This system can be driven in the high quality wood drying mode by using this control approach.

And in later half, the kiln temperatures and humidity correspond well with the schedule temperatures. Therefore, this control was confirmed as a success.

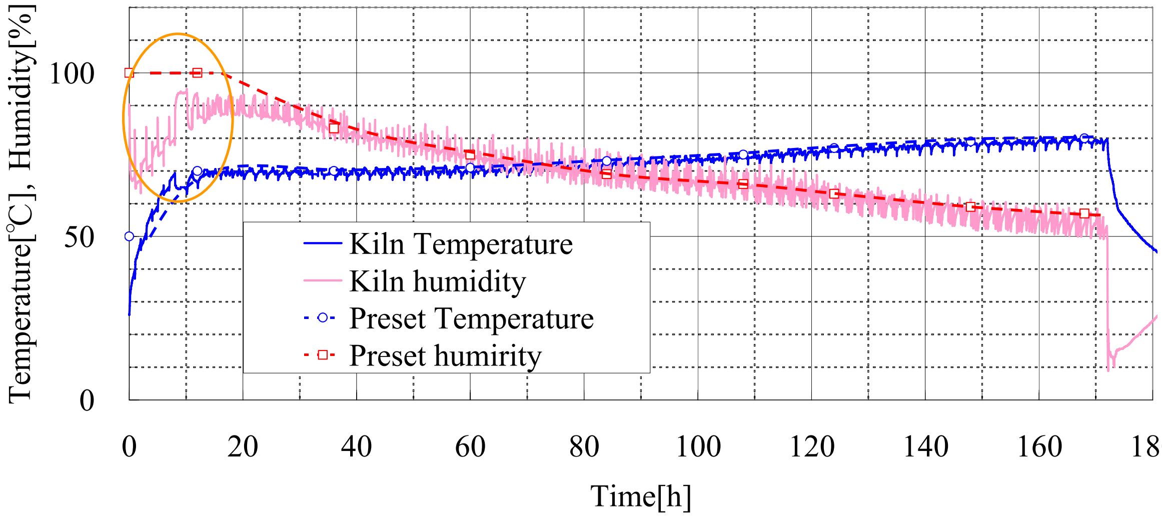

Fig.7 Time history of temperature and humidity on high speed mode

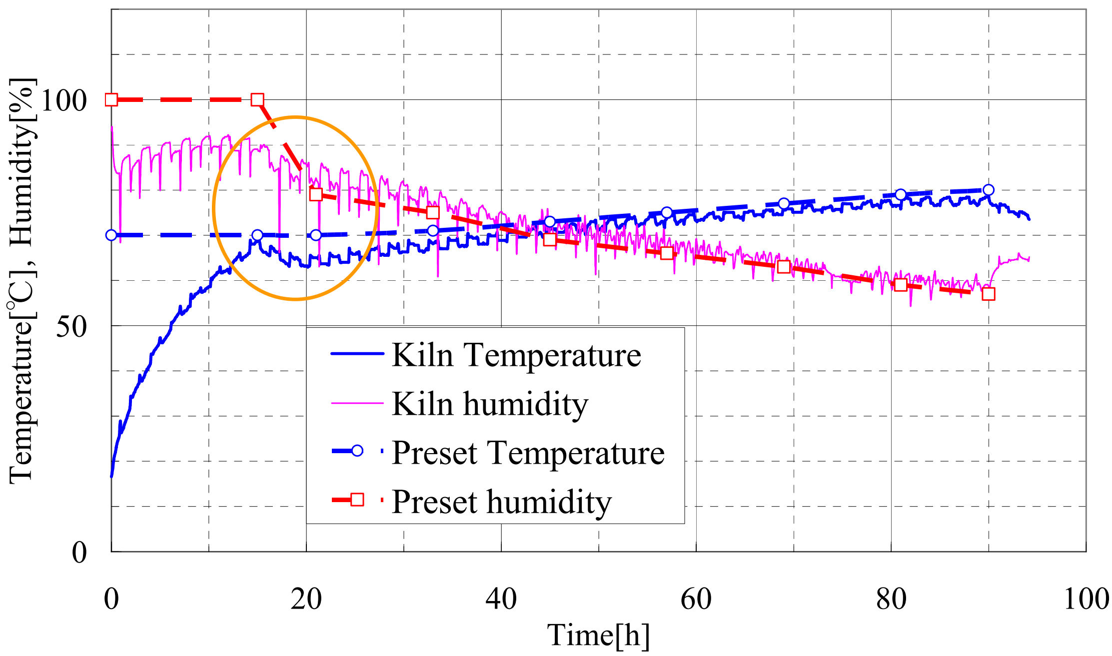

Fig.8 Time history of temperature and humidity on high quality mode

Table.2 Temperature and humidity schedule (Cryptomeria board)

Program step	1	2	3	4	5	6	7	8
Processing time[h]	12	24	24	12	12	12	12	12
Temperature[℃]	70	70	71	73	75	77	79	80
Humidity[%]	100	83	75	69	66	63	59	57
Absolute humidity[g/kg]	277	214	198	198	209	219	224	226

Table.3 Temperature and humidity schedule (Japanese cypress board)

Program step	1	2	3	4	5	6	7	8
Processing time[h]	15	6	12	12	12	12	12	12
Temperature[℃]	70	70	71	73	75	77	79	80
Humidity[%]	100	79	75	69	66	63	59	57
Absolute humidity[g/kg]	277	187	198	198	209	219	224	226

5.2 Dried wood moisture data

During drying of wood, two samples of wood were put in the Kiln and weighed every morning at 9 o'clock. Time history of wood moisture is shown in Figure 9. The two samples linearly lose weight as anticipated.

On the other hand, at the end of wood drying, a sample of dried wood was randomly chosen and the moisture content was measured. Figure 10 shows results of the moisture contents measured for various numbers of woods. The results show that most of the wood has a moisture content of less than 12%, the target value of this study.

In all the tests performed 90% of the dry wood had a moisture content of less than 12% with no crack or deformation defects to affect quality of the wood.

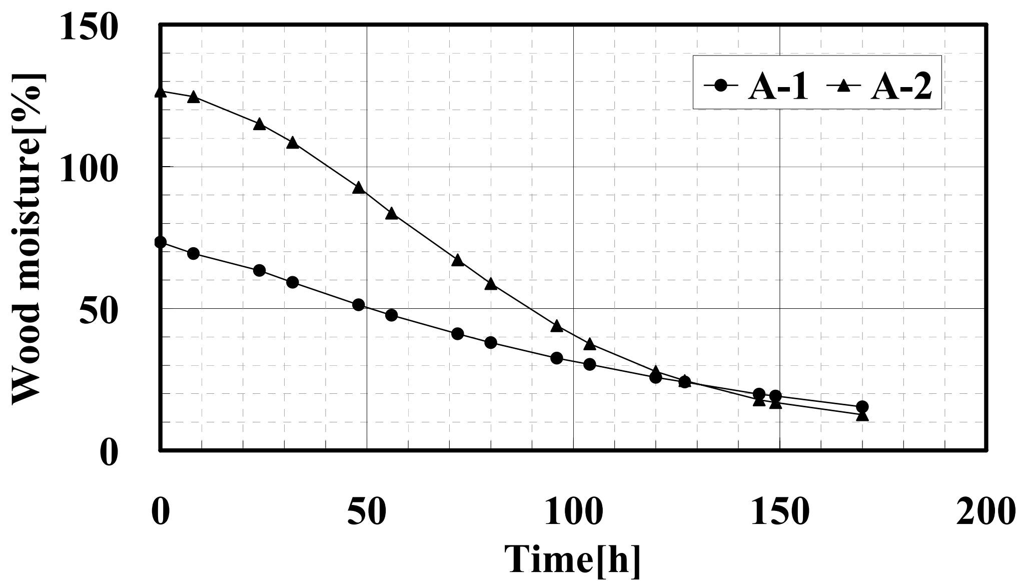

Fig.9 Time history of Wood moisture

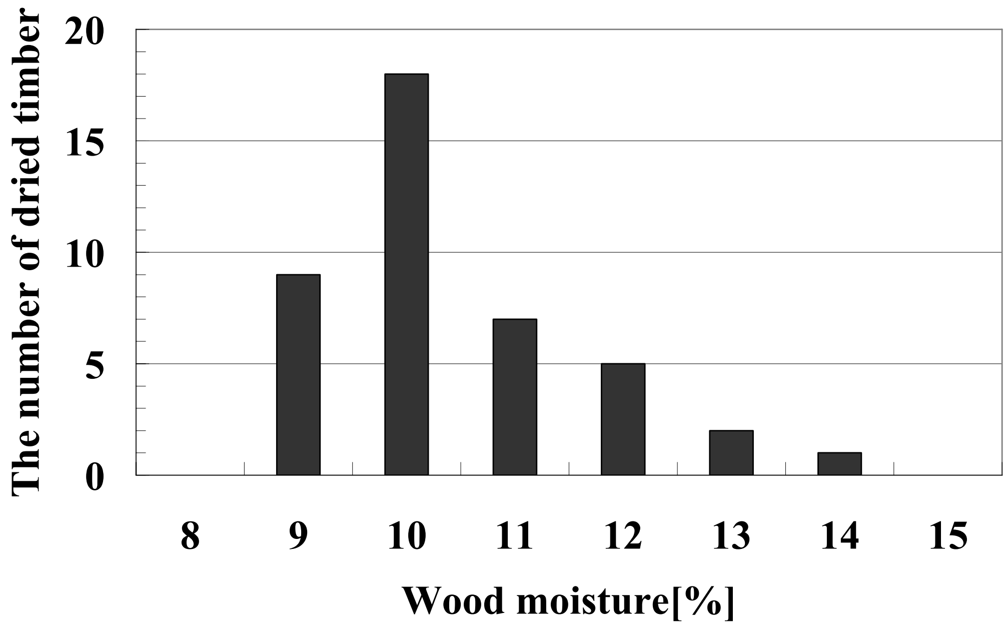

Fig.10 The number of dried timber for Wood moisture

6 CONCLUSION

This study has shown that a CO_2 heat pump system applied in wood drying can greatly reduce the amount of CO_2 emissions and running costs when compared to a fossil fuel fire boiler system. The CO_2 heat pump system incorporates humidity control thus improving the quality of dry wood.

The amount of CO_2 emissions (in Japan) in 2008 were 1.6%, in 2009 were -4.1% more compared with the 1990 levels. In order to reduce the emissions by 20% by 2050 further efforts are called for. In this regard the CO_2 heat pump is one of the alternative choices to fuel fired boilers. The CO_2 heat pump system regulates both temperature and humidity to offer high quality wood which is demand in the house construction industry. Further studies on improving efficiency, humidity during start up and cost reductions will be carried out.

7 ACKNOWLEDGMENT

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8 REFERENCE

Heat Pump and Thermal Storage Technology Center of Japan： Search report about economic effect by heat pump diffusion

http://www.tepco.co.jp/eco/report/glb/02-j.html

Environment Ministry： Order for Enforcement on the Act on Promotion of Global Warming Countermeasures

Institute of Energy Economics Japan Petroleum Information Centre： monthly survey of January 2009

Kimitaka KADOWAKI, Akito Machida, Kousaku NISHIDA, Masashi Kato, Shuetsu SAITO, Yukitaka KATO, 2010, “Development of a Kiln Dried Wood System using Heat Pump Technology”, Mechanical Engineering Congress 2010 Japan Proceedings Vol.3 ,p.125-126,

2010 Kimitaka KADOWAKI, Akito Machida, Kousaku NISHIDA, Masashi Kato, Shuetsu SAITO, Yukitaka KATO, 2010, “Development of a Kiln Dried Wood System using CO_2 Heat Pump Technology”, The International symposium on New Refrigerants and environmental technology 2010 proceedings p105-109

Please list all references according to the following examples.

Holman J.P. 1968. Heat Transfer, McGraw Hill, New York.

ASHRAE 1989. “ASHRAE Handbook-Fundamentals,” p. 367, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta.

Holzle A.M., D. M. Munson, E. A. McCullough, and F.H. Rohles, Jr. 1983. “A validation study of the ASHRAE summer comfort envelope,” *ASHRAE Transactions*, Vol. 90, Part 1B, pp. 126–138.