

Application of water-circulation type heat pump to lumber drying system

Takenobu Kaida^{a*}, Tsukasa Takayama^b, Hiroyoshi Kataoka^c

^aCentral Research Institute of Electric Power Industry, 2-6-1 Nagasaka, Yokosuka-shi, Kanagawa 240-0196, Japan

^bToshiba Carrier Corporation, 336 Tadehara, Fuji-shi, Shizuoka 416-8521, Japan

^cShimane Prefecture Mountainous Region Research Center, 1207 Kamikijima, Iinan-cho, Iishi-gun, Shimane 690-3405, Japan

Abstract

Lumber is used primarily as building material. Since freshly cut down lumber contains a large amount of water, it is necessary to dry it to constant moisture content for high quality. Currently, artificial drying method as typified by steam drying system has become the mainstream of lumber drying in Japan, but the existing system takes high equipment and energy costs. The aim of this study was to reduce energy cost and to save primary energy for lumber drying system by applying an industrial heat pump as a substitute heat source equipment. We built a prototype lumber drying system with a solar thermal collector, a water-circulation type heat pump and a waste heat recovery heat exchanger. This system had a 20m³ drying room about equal to an existing steam drying system with a heavy oil-fired boiler. As a result of experimental study, this system can reduce primary energy consumption by 56%, CO₂ emissions by 54% and energy cost by 60%, compared to the steam drying system, keeping the kiln-dried lumber quality high. In addition, we evaluated the energy performance of this system and obtained some design guides for commercialization of this system.

© 2017 Stichting HPC 2017.

Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.

Keywords: Water-circulation type heat pump ; Lumber drying system ; Primary energy saving ; Energy cost reduction

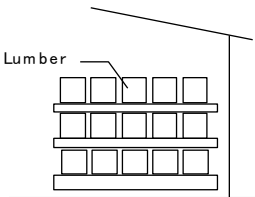
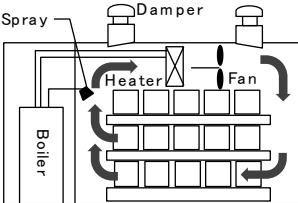
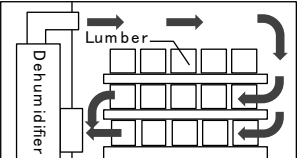
1. Introduction

Lumber is used primarily as building material. The use of lumber as building material accounts for approximately 80% of the total domestic lumber demand in Japan [1]. Since freshly cut down lumber contains a large amount of water, it is necessary to dry it to constant moisture content for high quality.

As shown in Table 1, lumber drying methods are generally known as examples of the natural drying method allowed by the weather conditions, the steam drying and the dehumidification drying. But these methods have problems in each: drying operating time, energy cost, quality of kiln lumber and so on. Currently, artificial drying method as typified by steam drying system has become the mainstream of lumber drying in Japan, but the existing system takes high equipment and energy costs. This prevents artificial drying systems from spreading widely.

Table 1. Existing typical lumber drying methods

* Corresponding author. Tel.: +81-46-856-2121; fax: +81-46-856-3346.
E-mail address: kaida@criepi.denken.or.jp.

	Natural drying method	Steam drying system	Dehumidification drying system
System			
Drying operation time	2~6 months	5~14 days	15~30 days
Water content	~30%	~20%	~20%
Installation cost	Low	High	High
Energy cost	Low	High	Low~Middle
Quality of lumber	Surface cracking	Internal cracking	Surface cracking

This study aims at middle temperature drying expected to apply heat pumps. We built a prototype lumber drying system with a heat pump and evaluated the effects of reducing energy cost, saving primary energy and quality of kiln lumber. In addition, we evaluated the energy performance of this system and obtained some design guides for commercialization of this system.

2. Middle temperature lumber drying system with heat pump

2.1. Prototype of lumber drying system

In the existing steam drying systems, as shown in Table 1, the drying room air is heated with the steam heat exchanger and is humidified with the directive steam spray. The room air temperature and humidity are controlled by the outside air and exhaust air dampers. In contrast, the prototyped drying system was heated with the hot water by the heat pump, and the room humidity was not controlled. Figures 1 and 2 show the external appearance and the schematic diagram of the prototyped drying system.

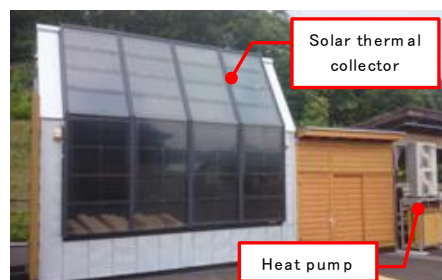


Fig. 1. External appearance of the prototyped lumber drying system

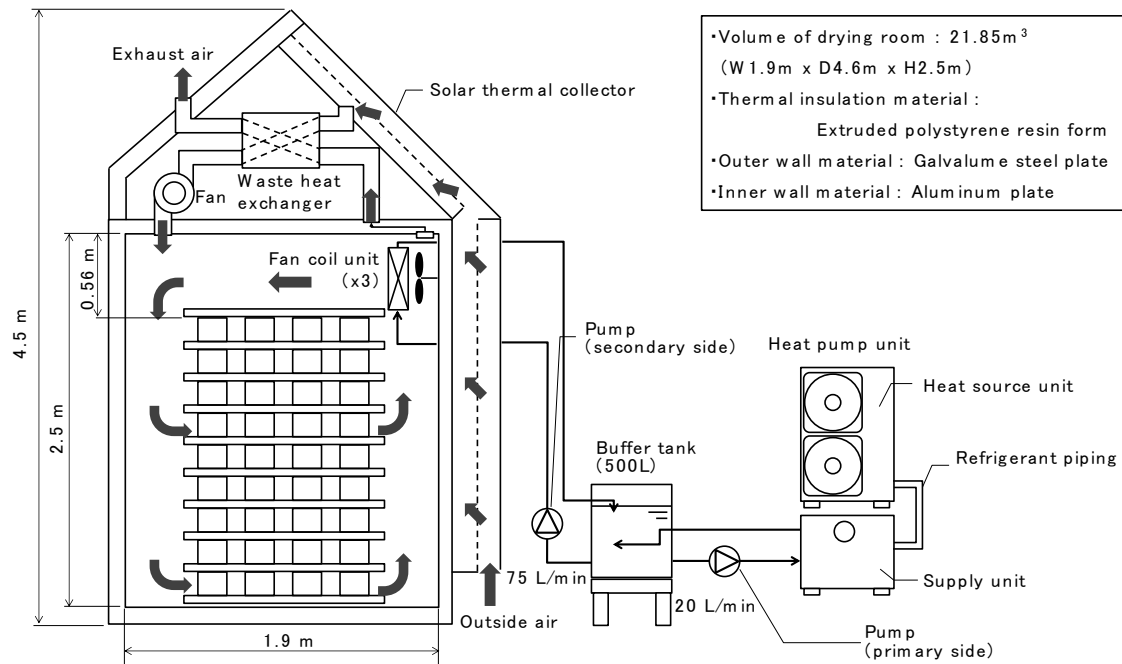




Fig. 2. Schematic diagram of the prototyped lumber drying system

The heat pump was installed outdoors and connected to the buffer tank (500L) similarly installed outdoors. By sending water with the primary side circulation pump, the heat pump kept the tank temperature constant. On the other hand, the hot water in the tank was sent to the three fan-coil units in the drying room and heated the room air. In this study, the room temperature was set at 60°C, for this, the sending water temperature from the heat pump to the tank was kept at 70°C based on the preliminary test results.

For realizing the 70°C circulation heating, the high temperature water-circulation type heat pump for industrial use [2] was used. As shown in Table 2, the heat pump consists of binary heat pump cycle with R410A (Heat source unit) and R134a (Supply unit) and can effectively operate the circulation heating over 50°C which was difficult using existing simple heat pump cycles.

Table 2. Specifications of heat pump [2]

	Heat source unit	Supply unit
External appearance		
Dimension (W x D x H) [mm]	900 x 320 x 1,340	900 x 320 x 700
Power supply	3 φ 200V (50Hz / 60Hz)	
Rated heating capacity [kW]	14.0	
Rated COP [kW / kW]	3.5*1	
Leaving water temperature [°C]	50 ~ 90	

*1 Ambient temperature: 25°CDB/21°CWB, Inlet water temperature: 60°C, Outlet water temperature: 65°C

In addition, the prototyped system had the solar thermal collector for using the daytime solar thermal effectively and had the waste heat exchanger for reducing the exhaust loss. The waste heat exchanger was a sensible heat exchanger commercially supplied for residential use.

2.2. Experimental method

The square lumber of the Japanese cedar was used as the tested material (Finishing size: 120×210×4,000, Number of tested lumber: 36). The drying schedule was as follows:

- High-temperature setting process [3] by using the steam drying system was conducted for 48 hours for decreasing the surface cracking,
- The tested lumbers were transferred to the prototyped drying system and the drying test was started,
- The drying operating time was set for 18 days based on the preliminarily tests so that the water content could finish below 20% on a dry-weight basis (equivalent to SD20 class of the Japanese Agricultural Standard [4]).

2.3. Experimental results

Figure 3 shows the daily mean measured data trends within the heat pump drying time. It took about two days to heat up the drying room air from the starting temperature 31°C to the target temperature 60°C. As mentioned above, in this study, the heat pump controlled the sending water temperature at 70°C. The averaged heating capacity of the initial 24 hour held at about 10kW, although the maximum heating capacity of the heat pump is about 25kW. It will be possible that the initial heat-up time is shortened by giving reactions as follows:

- Altering the controlled object from the heat pump sending water temperature to the fan-coil unit entering water temperature or the drying room temperature,
- Setting the heat pump sending water temperature with a programmable timer (for example, setting temperature 90°C for initial 24 hour and 70°C from then on).

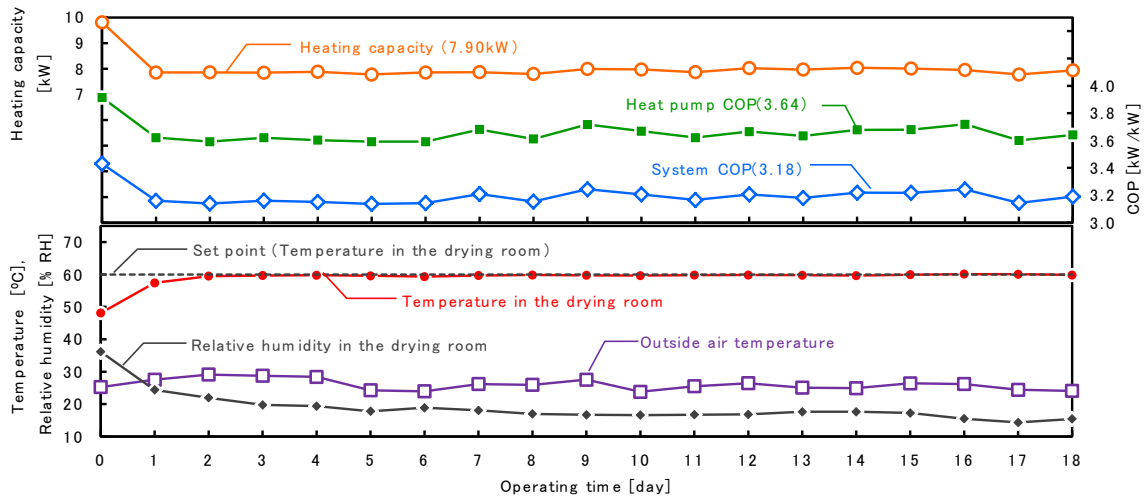


Fig. 3. Measured data (Daily mean)

On the other hand, after the 2nd day the drying room temperature was kept at about 60°C. The heating capacity after the day was about 7.9 kW (daily mean), that is, the demand heating capacity was lower than the rating heating capacity 14 kW. The heat pump COP was about 3.6, that is, the heat pump was operated efficiently. But considering the primary and secondary circulation pump input powers, the system COP during the heat pump operation decreased to about 3.2. It is important to reduce the circulation pump input powers.

Figure 4 shows the measured data trends at the representative day after the drying room temperature was stable. As mentioned above, since the demand heating capacity became low, the heat pump kept the room temperature at 60°C with repeating start and stop operations. The fan-coil unit entering water temperature was lower than the heat pump leaving temperature by 6~7 °C. This is probably due to a mixing of the fan-coil unit leaving water and the heat pump leaving water in the open buffer tank. There will be room for improvement on the buffer tank structure.

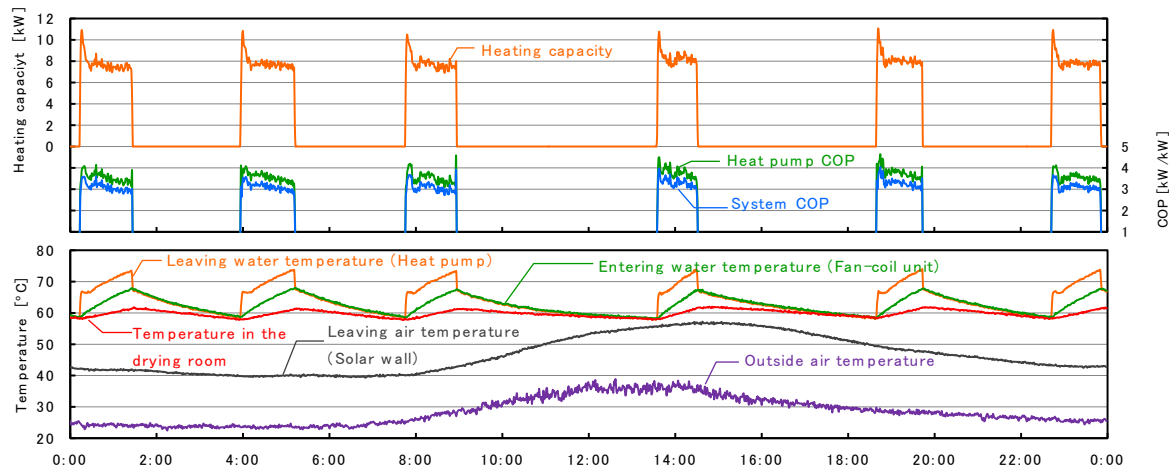


Fig. 4. Measured data (5th day)

Figure 5 shows the energy balance of the prototyped lumber drying system. From this figure, we analyzed the energy system in detail about each of the heat supply side and the heat load side.

The heat was supplied to the drying room from the heat pump, the solar thermal collector and the waste heat exchanger, respective heat supplied amounts were 318 kWh, 122 kWh and 44 kWh. The heat pump COP and system COP during 18 days was 3.2 and 2.1, respectively. Even while the heat pump stopping, the circulation pumps were operated and consumed wasteful electric power. It is important to reduce the unnecessary circulation pump input powers. The heat supply contributing ratio of the solar thermal collector and the waste heat exchanger were 11% and 4%, respectively. These options are low contribution and the payout times are long.

On the other hand, when focusing the heat load side, the amount of heat supplied to the drying room were 1116 kWh, but the amount of heat used to evaporating the water in the lumber were only 14% of that. The majority of the supplied heat was dissipated as radiation heat loss from the drying room wall. It is important to enhance the thermal insulation and air tightness and to improve the appropriate supply and exhaust air volume.

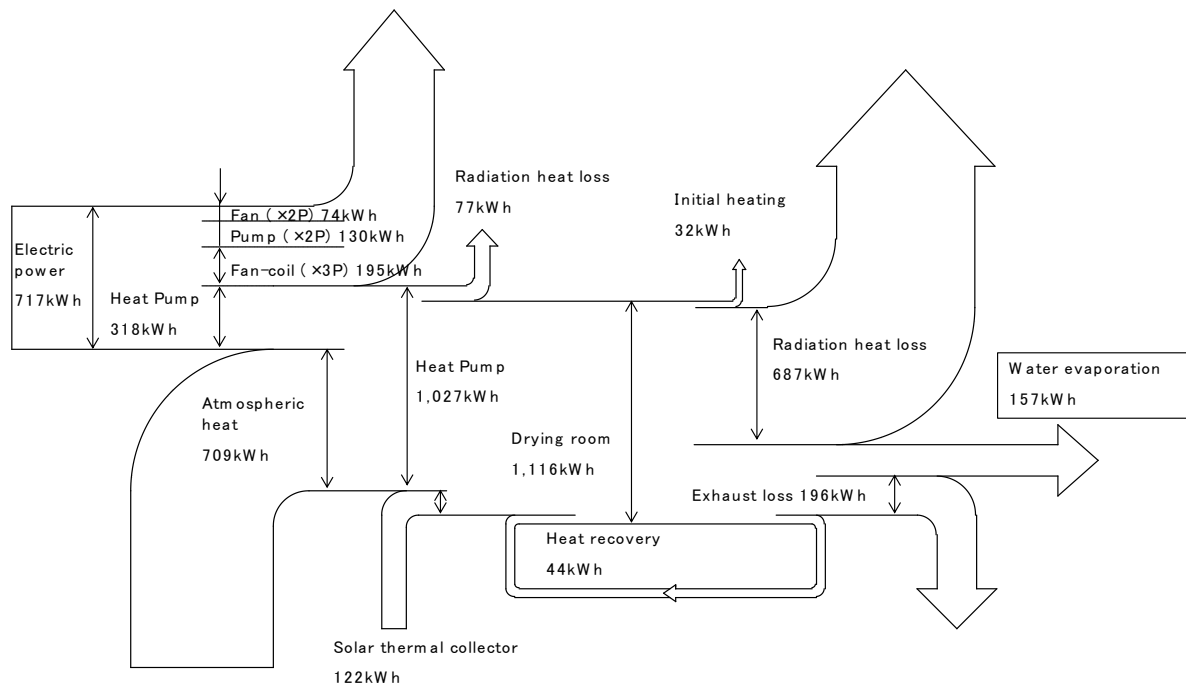


Fig. 5. Energy balance of the prototyped lumber drying system

3. Comparisons between prototype lumber drying systems and existing lumber dry systems

3.1. Experimental method

The natural drying and the steam drying were conducted in parallel for comparison with the above mentioned prototyped drying system. As is the case with the prototyped drying, the square lumber of the Japanese cedar was used as the tested material. For uniforming the initial water content, the tested lumbers were distributed to three lots (36 per lot) on the basis of the lumber weight after sawing.

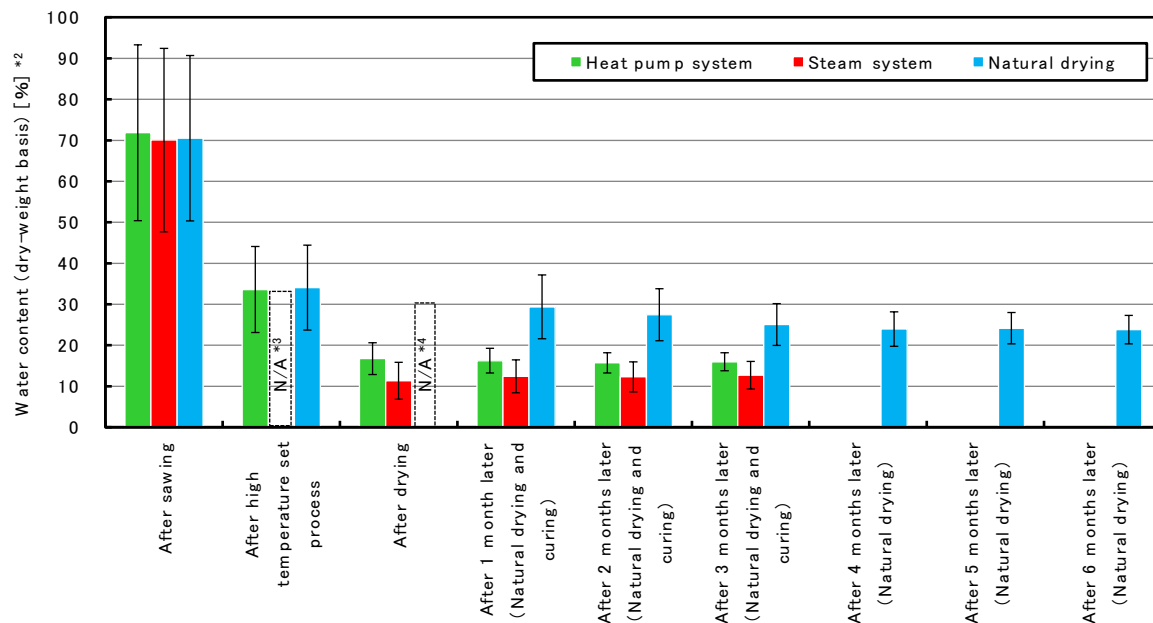
Table 3 shows the drying schedules of three drying methods. In common, the high-temperature setting process by using the steam drying system was conducted for 48 hours for decreasing the surface cracking. After the high-temperature setting process, the natural drying time was set for 6 months and the steam drying operating time was set for 12 days based on the existing drying schedule.

Table 3. Drying schedule

Drying method	Heat pump system	Steam system	Natural drying
High-temperature setting process	2 days		
Details of the process	STEP 1	Initial steam ing : 95°CDB x 12h	
	STEP 2	High temperature set : 120°CDB / 90°CWB x 24h	
	STEP 3	Temperature fall : 70°CWB x 12h	
Drying process	18 days	12 days	6 months
Drying (heating) temperature	60°CDB / -	90°CDB / 60°CWB	(Ambient temperature)

3.2. Experimental results

Figure 6 shows the transitions of the water content in each drying test. The water contents after sawing were about 70% and those after the high-temperature setting processes were about 35%. After each drying process, the heat pump system dried lumbers to the water content of 20% or under after 18 days operation and the steam system dried lumbers to the water content of about 10% after 12 days operation. But the natural system could not dry lumbers to the water content of 20% or under even after 6 months.



*2 The error bar shows the standard deviation of test materials.

*3 There is no measured data of the steam system.

*4 There is no process.

Fig. 6. Transitions of water content

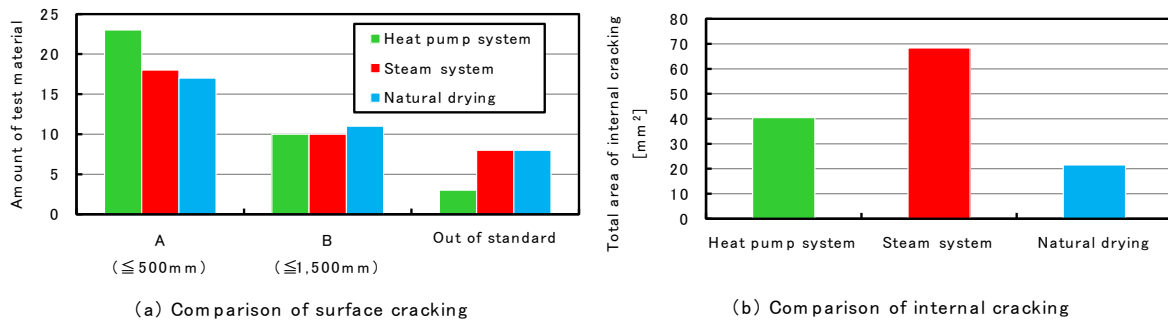


Fig. 7. Quality of kiln lumbers

Figure 7 shows the comparisons of the quality of the kiln lumbers. The surface cracking of the heat pump drying was the lowest of the three methods and the internal cracking of that was the second lowest after the natural drying. These results confirmed that the quality of the kiln lumbers by the heat pump drying was on a par with, or better than, the steam drying.

Table 4 shows the results of the primary energy consumptions, energy costs and so on with making comparisons between the heat pump drying system and the steam drying system. As mentioned in figure 6, the steam drying was over-drying, therefore the result was adjusted so that the finishing water content was 20%. As the result of the adjustment, the drying time of the steam system was modified to 9 days. Compared with the adjusted steam drying system, the heat pump drying system could reduce primary energy consumption by 56%, CO₂ emissions by 54% and energy cost by 60%, although the heat pump drying took about twice the drying time.

Table 4. Results of the comparative evaluation

		Drying method		
		Heat pump system	Steam system	Steam system (Adjustment)* ⁹
High temperature set process	Drying time	2 days	←	←
	A-type heavy oil consumption	150 L	←	←
	Primary energy consumption* ⁵	6.2 GJ	←	←
Drying process	Drying time	18 days	12 days	9 days
	Drying temperature	60 °C	90 °C	90 °C
	A-type heavy oil consumption	–	630 L	473 L
	Electric power consumption	522 kW h* ⁸	–	–
	Primary energy consumption* ⁵	26%	133%	100%
	CO ₂ emissions* ⁶	29%	133%	100%
	Energy cost* ⁷	21%	133%	100%
Total	Drying time	20 days	14 days	11 days
	Primary energy consumption* ⁵	44%	125%	100%
	CO ₂ emissions* ⁶	46%	125%	100%
	Energy cost* ⁷	40%	125%	100%

*⁵ Energy consumption rate: 9.76 MJ/kWh (Electric power), 41 MJ/L (A-type heavy oil).

*⁶ CO₂ emissions intensity: 0.70 kg-CO₂/kWh (Electric power), 2.71 kg-CO₂/L (A-type heavy oil).

*⁷ Applied with an actual value.

*⁸ The electric power consumption is total of a heat pump, 2 pumps and 2 blowers.

To compare with the steam drying system, the electric power consumption of fan-coil units will be excluded.

*⁹ The drying time of steam system is adjusted. (Because of over-drying)

3.3. Discussion

The primary energy efficiency of the heat pump drying system was 117% (=36.9% × 3.18). Assuming that the heat load of the steam drying system was equal to that of the heat pump system, the primary energy efficiency of

the steam system could be calculated as 52% from the primary energy consumptions. However the heat load of the steam system was not obtained, and the heat load would be not equal to that of the heat pump system because each of the drying room temperature was different. Most of the heat load was radiation heat loss and exhaust heat loss. These losses are proportional to the difference between the room temperature and outside temperature. Thus, the heat load of the steam system would be about 1.5 times as large as that of the heat pump system. The primary energy efficiency of the steam system would be about 77%. Therefore, the energy saving performance of the heat pump system derived from the substituting heat pump for steam boiler and the decreasing the heat load by lowering the drying room temperature.

4. Conclusion

For reducing energy cost and to save primary energy for lumber drying system by applying the water-circulation type heat pump as a substitute heat source equipment, we can conclude the following:

- The quality of the kiln lumbers by the heat pump drying is on a par with, or better than, the steam drying,
- Compared with the existing steam drying system, the heat pump drying system can reduce primary energy consumption, CO₂ emissions and energy cost by 56%, 54% and 60%, respectively,
- Although the heat pump drying takes about twice the drying time.

In addition, we obtained the following design guides for commercialization of this system:

- The solar thermal collector and the waste heat exchanger will be not equipped due to the low investment recovery effect;
- The damper will be adopted as the outside and exhaust air system, which will reduce radiation heat loss, exhaust heat loss and electric power consumption by not equipping blowers,
- It is necessary to reduce the unnecessary circulation pump input powers and to improve the buffer tank structure without mixing of the fan-coil unit leaving water and the heat pump leaving water in the tank.
- The initial heat-up time will be shorten by altering the controlled object from the heat pump sending water temperature to the fan-coil unit entering water temperature or the drying room temperature or by setting the heat pump sending water temperature with a programmable timer.

References

- [1] Annual report on forest and forestry in Japan, The Ministry of Agriculture, Forestry and Fisheries of Japan, 2015. [in Japanese]
- [2] Takayama, T., Suzuki, H., Iwata, Y., Miyaoka, Y., Nishiyama, T. and Numata S., 2014. "Development of High Temperature Water Circulation Type Heat Pump for Industries", 11th IEA Heat Pump Conference, Montreal, Canada, paper#AO193.
- [3] Manual of safe and untroubled kiln lumber product and use, For realizing non internal cracking kiln lumber products, 2012. [in Japanese]
- [4] Japanese Agricultural Standard (JAS), The Ministry of Agriculture, Forestry and Fisheries of Japan, 2013. [in Japanese]