COMBINATION OF WASTE-HEAT-RECOVERY HEAT PUMP AND AUXILIARY SOLAR-ENERGY HEAT SUPPLY PRIORITY FOR TOBACCO CURING

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Abstract. Extensive management of tobacco curing facilities can lead to fuel waste and environmental pollution. In this study, a new integrated equipment controlled by a microcomputer is proposed and built, including a flat panel solar-collector heating system located on the unoccupied flat rooftops of a bulk curing barn, a heat-pump heating system, and a heat-pump-type dehumidification system. Test results show that from 10:00 am to 3:00 pm, under sunny or partly cloudy weather during tobacco season, the air temperature in the flat-panel solar collector exceeds 68 °C, which is higher than the highest dry-bulb temperature required for tobacco curing. Compared with an existing air-source heat pump heating system in the barn, a curing cost saving of 21% per kilogram of dry tobacco leaves is achieved. Because of waste-heat recovery for recycling and solar energy heating, the operating time of the new device heating compressor is approximately 70.6 h during a curing time of 142 h, which is less than the control compressor, i.e., 115.8 h. The heat pump dehumidification system controls the difference between the actual wet-bulb temperature and target wet-bulb temperature of the barn to be within 0.5 °C.

Keywords: *hot air drying, dehumidifier, precision control, dry-bulb and wet-bulb temperature, bulk curing barn*

Introduction

Flue-cured tobacco is dried by fire in a process generated inside a furnace and the heat is transferred through the flue pipes laid in a strategic position inside an airtight barn where the leaves are hung (Truong et al., 2016). The large-scale use of coal fuel for tobacco curing can result in environmental degradation (Li et al., 2017; Wang et al., 2015). In recent years, with serious haze weather conditions occurring frequently in North China and more than 30% (2.3 million ton) of flue-cured tobacco leaves produced in China, air pollution caused by coal burning and heating used for conventional tobacco curing has received significant attention (Liu et al., 2016; Mana and Fatt, 2017). The government attaches considerable importance to the use of clean energy for tobacco curing and emission reduction (Xiao et al., 2015).

Literature Review

Solar energy is an abundant, renewable, and sustainable energy source that has attracted several eminent researchers globally to work in the field of solar energy applications for flue-cured tobacco leaves (Kumar et al., 2016; Patil and Gawande,

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2016). From 1974 to 1986, Huang and Bowers Jr. (1986) developed two types of solar greenhouse designs namely the load supporting wall type and the shell type for tobacco curing. Janjai et al. (1986) investigated the technical feasibility of using solar energy for flue curing of tobacco in a bulk barn. Subsequently, Indian tobacco operators built a solar barn in Lajiawang, Delhi, which could save 43%–45% fuel (Subramaniam et al., 1998; Randrianarison and Ashraf, 2017). China is one of the first countries to use solar energy for tobacco curing. With the extensive application of bulk curing barns since 2008, a few researchers built a solar heating system on the unoccupied roof of a barn that was used only in the tobacco yellowing period (Lu et al., 2011). Limited by monolithic computer technology, the early solar energy system used for flue curing of tobacco was relatively simple and could not be controlled accurately.

Heat pump technology was first introduced in Germany in 1930, and it was rapidly applied and promoted in all fields (Carl, 1933). Owing to its significant advantages, such as energy-saving and reduced emissions, heat pump drying became widely used in the industry (Bao and Wang, 2016). Gong and Pan (2003) were the first to use the heat pump technology to provide independent heat for tobacco curing, and they built numerous barns that were heated using a heat pump in a few tobacco planting areas in China. Heat pump dehumidification led to recovery of waste heat for recycling (Ahn et al., 2016; Chantoiseau et al., 2016). A heat-pump dehumidifier was used by Maw et al. (2004) in 1999 for the first time for tobacco curing, which was only applied during the lamina and stem drying phases (Wu et al., 2017).

Based on the above literature, a device that combined a waste-heat-recovery heat pump with an auxiliary solar-energy heat supply priority for tobacco curing was developed for use in a single bulk curing barn. Through precise control of curing process parameters, the objective was using the adequate solar energy during the season of tobacco plant harvest and the recycling of heat from the high temperature moist air during the tobacco curing process to cure tobacco leaves.

Materials and methods

Equipment structure

The integrated energy-heating equipment consists of a heating structure with a distinct appearance (*Figure 1*), which includes a solar air heating system, a heat pump heating system, a heat pump dehumidification system, a microcomputer, and other components. The equipment power supply is 380 V. In China, the basic structure and specifications of a bulk curing barn were established by the State Tobacco Monopoly Administration on April 18, 2009 (hereinafter referred to as barn no. 418) (TSBCN, 2009). The overall size of the barn was 11440 × 2700 × 3500 mm (length × width × height).

The solar air heating system is located on the unoccupied flat rooftops of a bulk curing barn, which is comprised of a flat-panel solar collector (1), a solar hot air chamber (SHAC) (2), an outlet duct for lower temperature air (3), an intake duct for higher temperature air (4), a centrifugal fan (11), etc. Air is the energy carrier medium in the solar air heating system. The centrifugal fan interactively drives airflow between SHAC (2) and the heating chamber to utilize solar energy. It is hermetically connected to the end of the outlet duct for lower temperature air (3). The flat-panel solar arrays are installed facing south and oriented at an angle of 6° to the horizontal. Each barn consists of eight flat-panel solar-collector arrays with dimensions of 3200 × 1200 × 60 mm (length × width × height), which are connected in series through an insulation board and airflow pipeline. As a result, one barn with eight arrays forms a solar energy collecting area of 28.8 m^2. Special heat insulation is provided on the roof of the SHAC (2) using a double-glazed organic transparent glass with a thickness of 4 mm and a black multilayer absorbing metal net (23) that is suspended below the glass layer. On the outlet duct for lower temperature air (3), air outlets (22) for different sections have circular holes with different diameters depending on the wind pressure generated by the centrifugal fan (11). Each SHAC is connected in series through the outlet duct for lower temperature air (3) and the intake duct for higher temperature air (4) (*Figure 2*).

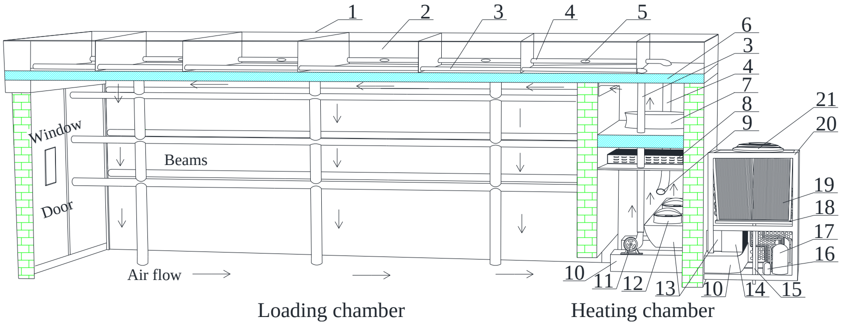

Figure 1. *Structure of the integrated energy-heating equipment.*

Note: 1. Flat-panel solar collector, 2. Solar hot air chamber (SHAC), 3. Outlet duct for lower temperature air, 4. Intake duct for higher temperature air, 5. Hot air inlet, 6. Roof of bulk curing barn, 7. Circulating fan, 8. Reflux condenser, 9. Pipeline exit for solar hot air after heating, 10. Cabinet for moist air entry from the loading chamber, 11. Centrifugal fan, 12. Fan I with a spring cap, 13. Cabinet for dry air outlet after dehumidification, 14. Evaporator I for dehumidification, 15. Pipeline for directing flowing water outside, 16. Compressor I for dehumidification, 17. Compressor II for heating, 18. Channel for flowing water, 19. Evaporator II for heating, 20. Outdoor equipment frame, 21. Fan II for external heat exchange.

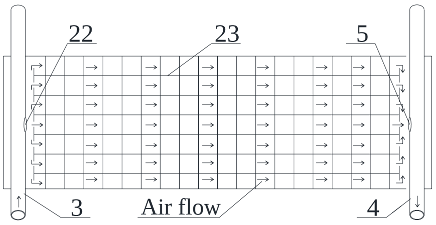

Figure 2. *Internal structure of SHAC.*

Note: 22. Air outlet, 23. Black multilayer absorbing metal net.

In the reflux condenser (8), there are two sub-condensers for heat pump heating and heat pump dehumidification drying, which share a heat pipe fin and the structural frame of the equipment. However, the condensate pipes of the sub-condensers are separated. The reflux condenser (8), compressor I for dehumidification (16), evaporator I for dehumidification (14), two cabinets for moist air entry from the loading chamber (10), two cabinets for dry air outlet after dehumidification (13), and two fans I with spring caps (12) constitute the waste heat recovery recycling system of the heat pump dehumidification system. The dehumidification system is operated in a closed loop, in which the air inside the barn is dehumidified and re-circulated. During dehumidification, heat is generated and accumulated in the barn. In this manner, higher internal temperature and lower relative humidity are achieved, as compared to the case in which fresh ambient air is used and higher temperature air with higher relative humidity is discharged. Evaporator I for dehumidification (14) is the connection point between the two cabinets for dry air outlet after dehumidification (13) and the two fans I with spring caps (12). Compressor I for dehumidification (16) is composed of two single 2.94-kW·h compressors (Emerson Climate Technologies, the same as below). When tobacco leaves in the barn require dehumidification during the curing process, the two fans I with spring caps (12), which are controlled by the microcomputer, start working. Moreover, the caps of the fans open under wind pressure and cause moist air, which is flowing from the loading chamber to the heating chamber, to flow into two cabinets for moist air entry from the loading chamber (10). Moist air is dehumidified by evaporator I for dehumidification (14), and it returns to the heating chamber through the cabinet for dry air outlet after dehumidification (13). Subsequently, the microcomputer stops the two fans I with spring caps (12), and their caps fall down under gravity.

The heat pump heating system is composed of a reflux condenser (8), a pipeline for directing flowing water outside (15), compressor II for heating (17), a channel for flowing water (18), evaporator II for heating (19), fan II (21), etc. Compressor II for heating (17) is composed of two single 2.94-kW·h compressors and two single 4.42-kW·h compressors.

To facilitate the operation of the integrated energy-heating equipment and precisely control tobacco curing, the microcomputer is designed based on curing requirements. The electronic control valve for throttling service is adopted to realize efficient heating and dehumidification of the heat pump.

Working principle

The working principle of the integrated energy-heating equipment is shown in *Figure 3*. The equipment has three independent and coordinated systems for providing heat. Solar energy provides auxiliary heating energy to preferentially assist the heating for tobacco curing. Moreover, energy from the ambient atmosphere, which is independent of the heat pump, primarily provides heat for tobacco curing. The heat pump dehumidifies moist air and recovers waste heat for tobacco curing. The conversion of energy in the three heating cycles is accomplished using the microcomputer operated by a tobacco curing technician.

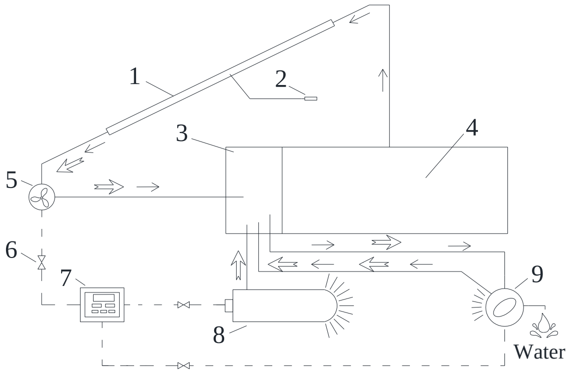

Figure 3. *Schematic of the system’s operating principle.*

Note: 1. SHAC, 2. Valve for air pressure relief, 3. Heating chamber, 4. Loading chamber, 5. Centrifugal fan, 6. Control electronic signal, 7. Microcomputer, 8. Air source heat pump heating, 9. Heat pump dehumidification. Note, “⇐” Heat flow direction; "←” Hot air flow direction.

The heat supply mode is controlled by the microcomputer as follows: 1) The difference between the actual dry-bulb temperature in the curing barn and the target dry-bulb temperature set by the microcomputer is -0.5–0.5 °C. In this case, if the air temperature in the SHAC is more than 10 °C higher than the target dry-bulb temperature, hot air heated through solar heating is driven preferentially by the centrifugal fan through wind pressure to the heating chamber. Then, it is transported by the circulating fan to the loading chamber. Moreover, if the temperature of the SHAC is not more than 10 °C higher than the target temperature, the solar air heating system stops providing heat to the heating chamber, and the heat pump heating system starts working and absorbs heat for tobacco curing from the ambient atmosphere. 2) The actual dry-bulb temperature in the curing barn is lower than the target dry-bulb temperature set by the microcomputer by 0.5 °C. In this case, if the air temperature in the SHAC is more than 10 °C higher than the target dry-bulb temperature, the solar hot air system and heat pump heating system provide heat for tobacco curing. Furthermore, if the air temperature in the SHAC is not more than 10 °C above the target dry-bulb temperature, only the heat pump heating system works. 3) The actual dry-bulb temperature in the curing barn is higher than the target dry-bulb temperature set by the microcomputer by 0.5 °C. In this case, the solar hot air system and the heat pump heating system stop working simultaneously.

According to the requirements of tobacco curing, the heat pump dehumidification system, i.e., evaporator I, converts the excessive water in the high humidity air of the barn into liquid water, while the heat in moist air is recovered for recycling through the reflux condenser in the heating chamber.

To maintain the high efficiency of the heat pump dehumidification system, the speed of fan I is controlled by a variable frequency power, and it is changed at the wet-bulb temperature points from 38–68 °C. The variable speed of fan I can control the ventilation flow between the cabinets for the entry of moist air from the loading chamber and the cabinets for dry air outlet after dehumidification, which could reduce the frost on evaporator I for dehumidification and condense a significant amount of water in the liquid state.

System operation test

The experiment was conducted in the experimental field of the Xuchang branch campus of Henan Agricultural University in 2015 and 2016 (N34°09，E113°49). The curing season typically lasts for 7–9 months, and it is primarily sunny with few rainy days.

Experimental treatment

Three single bulk curing barns (no. 418) with air descent were employed. Barn A was installed with the integrated energy-heating equipment. To facilitate experimental comparison, the equipment in barn B was a conventional heat pump that provided independent heating, and that in barn C was a coal burning furnace, which is widely used locally. Only the heating equipment was different between barns B and C, which had a conventional ventilation-based dehumidifying pattern in which fresh ambient air enters and high temperature moist air is discharged. The mature upper leaves of flue-cured tobacco of cultivar Zhongyan 100, with a uniform quality, were picked simultaneously and hung using the same type of clips used to hang tobacco. The error in the weight of the loaded green tobacco in barns A, B, and C was controlled to be ±50 kg.

The tobacco curing technology was in accordance with the curing process used in local bulk curing barns.

Basic performance test

When the three single barns started to cure tobacco simultaneously, the target dry-bulb temperature and target wet-bulb temperature (both set by the microcomputer), the air temperature in the SHAC, and the actual wet-bulb temperature in the loading chamber of barn A, were recorded at 1 h intervals from 6:00 am to 8:00 pm.

Working characteristics of system components

Intelligent electric parameter test instruments (Zurui, EPM6600-T) were employed to detect the electric energy consumption and operating time of the circulating fan, compressor I for dehumidification, compressor II for heating, centrifugal fan, fan I with a spring cap, and fan II for external heat exchange. The curing time was recorded, and the moisture lost from tobacco after curing was calculated by measuring the weights of green tobacco and dried tobacco after curing.

Grades and grade indices of cured tobacco

Fifty representative clips of cured tobacco were selected per batch per barn from the same position. Grades were assigned to the selected samples of tobacco by the graders of Tobacco Henan Industrial Company Limited. Grading was performed based on the indices of quality of appearance, which include proportions of superior tobacco, orange tobacco, and lemon tobacco, and whether tobacco leaves are green or black (GB2635-92, 1992).

Results

Heating coincidence degree between the solar energy provided and the tobacco curing required

Figure 4 shows the difference between the heat provided by solar energy and that required for tobacco curing in terms of the target dry-bulb and SHAC temperatures.

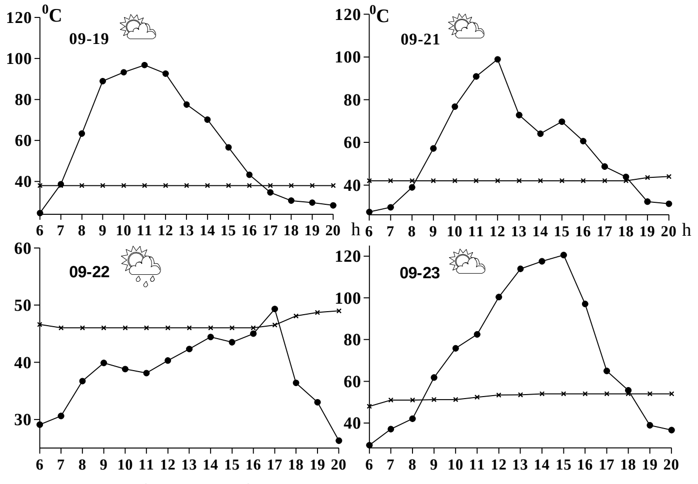

Figure 4. *Changes in target dry-bulb temperature during tobacco curing and air temperature in SHAC.*

The flat-panel solar collector receives solar energy radiation, and the air temperature in the SHAC rises and fluctuates between ambient temperatures and 120.5 °C. Except in the case of rainy and cloudy weather on 22 September, the air temperature in the SHAC is higher than the target dry-bulb temperature set by the microcomputer from 9:00 am to 5:00 pm, which shows that solar energy could provide heat for tobacco curing. From 10:00 am to 3:00 pm, solar radiation is the most abundant, and the air temperature in the SHAC is considerably higher than the highest temperature (68 °C is the highest dry-bulb temperature required for tobacco curing), which could provide heat during the entire tobacco curing process.

Effect of heat pump controlled dehumidification on tobacco curing

Figure 5 shows effect of heat pump controlled dehumidification on tobacco curing. According to the requirements of tobacco curing, when the wet-bulb temperature is required to remain constant, the actual wet-bulb temperature fluctuates consistently around the target wet-bulb temperature at regular intervals, such as on September 21 and 22. When the wet-bulb temperature is required to rise in the loading chamber, the actual wet-bulb temperature increases, remaining close to the target wet-bulb temperature, such as on September 23. Thus, based on the requirements of tobacco curing, the actual wet-bulb temperature could be controlled by the heat pump dehumidification system to be within ± 0.5 °C of the target wet-bulb temperature.

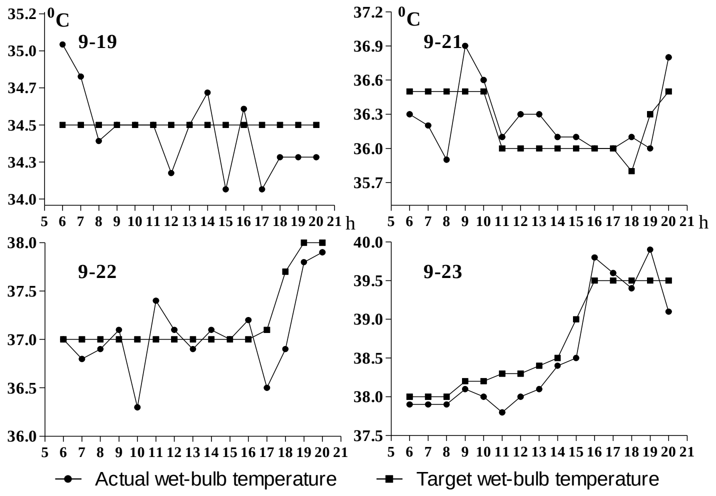

Figure 5. *Change in actual wet-bulb temperature and target wet-bulb temperature.*

Operating characteristics of equipment components

The test results (*Table 1* and *Table 2*) show that the operating time of the heat pump heating system (70.6 h) in barn A is considerably lower than that of the compressor for heating in barn B (115.8 h). The total operating times for barns A and B are 142 h and 141 h, respectively. The heat pump dehumidification system in barn A consumes 347.4 kW power to remove 3815 kg moisture from the tobacco leaves after curing, which is equivalent to 1 kW power for dehumidifying 10.98 kg water from moist air. The curing costs per barn for barns B and C are close to each other; however, they are higher than that for barn A. For the same heat pump heating for tobacco curing, barn A saves 21%

more curing cost than barn B. This suggests that a large amount of heat is lost from barns B and C during the curing process through discharge of hot moist air. With the closed loop operation of the heat pump dehumidification system in barn A, the air from the barn was dehumidified and recirculated, thus attaining a higher internal air temperature and lower relative humidity than is possible by taking in fresh air. Combined with solar energy assisted heating, this could reduce the cost of tobacco curing.

Table 1. *Comparison of equipment operation between barns A, B, and C.*

		Operating hours (h)	**Working power (kW·h)**	**Consumed power (kW)**	**Ratio of energy consumption (%)**	**Energy consumption (Yuan/barn)**	**Curing cost (Yuan/kg)**
Barn A	Compressor I for dehumidification	96.5	3–5	347.4	30.35	744.11	1.03
	Compressor II for heating	70.6	7–13	451.84	39.47		
	Circulating fan	143	1.5–2.2	191	16.68		
	Fan I with the spring cap	70	0.8	79.8	6.97		
	Fan II for external heat exchange	74.6	0.4	21.84	1.91		
	Centrifugal fan	66	0.8	52.8	4.62		
Barn B	Compressor for heating	115.8	8–15	1134.84	85.66	861.15	1.25
	Centrifugal fan	142	1.5–2.2	190	14.34		
Barn C	Coal burning	-	-[a]	-	82.54	810.31	1.24
	Fan for help fuel burning	90	0.13	11.7	0.94		
	Centrifugal fan	153	1.5–2.2	206	16.52		

Note：[a] =1393 kg. The local coal price was 480 Yuan/t in 2015, 2016. The price of electricity was 0.65 Yuan/kW. "-" blank data.

Table 2. *Statistics of the basic curing conditions for barns A, B, and C.*

	Curing time (h)	**Weight of green tobacco (kg)**	**Weight of dried tobacco after curing (kg)**	**Moisture lost from tobacco after curing (kg)**
Barn A	143	4484	669	3815
Barn B	142	4468	670	3798
Barn C	154	4438	632	3806

Tobacco quality after curing

Table 3 shows the appearance quality of flue-cured tobacco after curing. The tobacco appearance quality for barns A and barn B is better than that for barn C, which is primarily reflected by a higher orange-yellow tobacco proportion, less tobacco leaves with green or black colors, higher proportion of superior tobacco, and increased average selling price.

Table 3. *Analysis of the appearance quality of tobacco leaves.*

	Orange tobacco proportion (%)	**Lemon tobacco proportion (%)**	**Green or black tobacco leaves (%)**	**Proportion of superior tobacco (%)**	**Average price of cured tobacco (Yuan/kg)**
Barn A	81.8	14.6	3.6	41.6	22.4
Barn B	81.4	14.8	3.8	41.5	22.3
Barn C	76.5	19.2	4.3	37	20.5

Note: Yuan - Monetary unit in China.

Discussion

New device technology and precision control tobacco curing

The new device, which is a mature electrical industrial product integrated with solar collector, heat pump heating and heat pump dehumidification technology, used in this study can accurately and steadily control the dry-bulb and wet-bulb temperature of air according to curing process parameters, which is particularly advantageous for the synthesis and degradation of inner substances in tobacco leaves. Empirical addition of fuels and fuels combustion characteristics can adversely affect tobacco curing in production (Frey et al., 2003). Typically, heat for tobacco curing is provided by burning of fuels, such as coal or firewood, through manual labor and automatic fuel combustion under natural conditions (Truong et al., 2016; Tippayawong et al., 2006), which bring the large difference between the actual dry and wet-bulb temperature and target dry and wet-bulb temperature of the barn during tobacco curing process. This result is also consistent with the observation of Gong and Pan (2003) using a precise control equipment to cure tobacco.

Utilization prospect of solar energy resources in China

Solar irradiation and collecting area are the two main factors effecting solar-energy collection efficiency (Chow, 2010). *Figure 6* shows the distribution of solar radiation and the tobacco growing regions in China. From July–September, the daily total radiation at the experimental station in Xuchang was 18.55–23.33 MJ/m^2, which belongs to a general resources region. In certain provinces, such as Yunnan and Liaoning, solar energy resources are more abundant, and the design and installation of solar energy collectors at the top of barns should be considered for tobacco curing. Solar collection efficiencies above 94 % have recently been achieved (Sabiha et al., 2015; Verma et al., 2015) and many policies that encourage use of green energy have been issued by the government (Wang et al., 2015; Xiao et al., 2015). These have great significance for fossil-fuel energy savings in the tobacco curing industry in the near future.

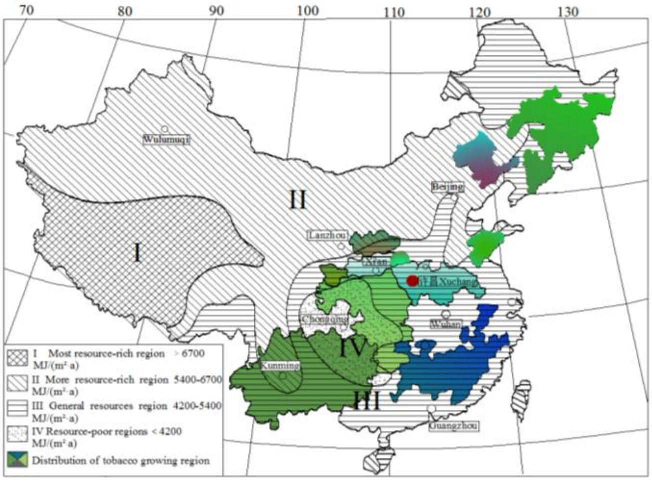

***Figure 6.** Distribution of solar radiation and tobacco growing regions in China.*

Note：“●” Location of the experimental point. The data sources are obtained from China's solar energy distribution and China tobacco plan.

Conclusion

This study proposed an integrated energy-heating equipment that could accomplish preferential solar energy assisted tobacco heating, which primarily consisted of heat pump heating and utilization of heat recycled from heat pump dehumidification. The equipment has the advantages of compact combination, precise control, and it is suitable for the popularization of a few tobacco planting areas. The experimental results show that in general resource regions with sunny days or partly cloudy days, solar energy could be efficiently used to provide heat for tobacco curing during the entire curing process. Heat pump dehumidification technology can discharge excess water in barns and recycle the heat from high temperature moist air. Using the equipment to cure tobacco can improve the appearance quality of the tobacco leaves and reduce the curing cost per kg of dry tobacco by 21% when contrasted to coal-fired curing. Thus, this device that can remove about 3500 kg of water in 142 h from this study may be suitable to use for drying other agricultural products after transformed.

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REFERENCES

[1] Ahn, J. H., Lee, J. S., Baek, C., Kim, Y. (2016): Performance improvement of a dehumidifying heat pump using an additional waste heat source in electric vehicles with low occupancy. – Energy 115: 67-75.

[2] Bao, Y., Wang, Y. (2016): Thermal and moisture analysis for tobacco leaf flue-curing with heat pump technology. – Procedia Engineering 146: 481-493.

[3] Carl, G. M. (1933): Heat pump. – US patent. Patent No:1,900,656.

[4] Chantoiseau, E., Migeon, C., Chasseriaux, G., Bournet, P. E. (2016): Heat-pump dehumidifier as an efficient device to prevent condensation in horticultural greenhouses. – Biosystems Engineering 142: 27-41.

[5] Chow, T. T. (2010): A review on photovoltaic/thermal hybrid solar technology. – Applied Energy 87(2): 365-379.
[6] Frey, H. H., Peters, B., Hunsinger, H., Vehlow, J. (2003): Characterization of municipal solid waste combustion in a grate furnace. – Waste Management 23(8): 689-701.
[7] GB2635-92. (1992): Chinese grade index for flue-cured tobacco. – China National Tobacco Corporation.
[8] Gong, C. R., Pan, J. B. (2003): Heat pump type of auto-control equipment for tobacco leaf flue-curing. – Transactions of the CSAE 19(1**)**: 155-158.
[9] Huang, B. K., Bowers Jr, C. G. (1986): Development of greenhouse solar systems for bulk tobacco curing and plant production. – Energy in Agriculture 5(4): 267-284.
[10] Janjai, S., Guevezov, V., Daguenet, M. (1986): Technico-enconomical feasibility of solar-assisted Virginia tobacco curing. – Drying Technology 4(4): 605-632.
[11] Kumar, M., Sansaniwal, S. K., Khatak, P. (2016): Progress in solar dryers for drying various commodities. – Renewable & Sustainable Energy Reviews 55: 346-360.
[12] Li, H., Dong, L., Xie, Y., Fang, M. (2017): Low-carbon benefit of industrial symbiosis from a scope-3 perspective: a case study in China. – Applied Ecology and Environmental Research 15(3): 135-153.
[13] Liu, G., Yang, Z., Chen, B., Zhang, Y., Su, M., Ulgiati, S. (2016): Prevention and control policy analysis for energy-related regional pollution management in china. – Appl. Energy 166: 292-300.
[14] Lu, Y. H., Xu, T. Y., He, B. (2011): Application effect of solar auto-control bulk curing barn. – Hubei Agricultural Sciences 50(23): 4934-4936.
[15] Mana, S. C. A., Fatt, N. T. (2017): Arsenic speciationusing ultra high-performance liquid chromatography and inductively coupled plasma opticalemission spectrometry in water and sediments samples. – Geology, Ecology, and Landscapes 1(2): 121-132.
[16] Maw, B. W., Moore, J. M., Stephenson, M. G., Sumner, P. E. (2004): Heat pump dehumidification during the curing of flue-cured tobacco. – The proceedings of the 41st tobacco workers' conference. Nashville, Tennessee.
[17] Patil, R., Gawande, R. (2016): A review on solar tunnel greenhouse drying system. – Renewable & Sustainable Energy Reviews 56: 196-214.
[18] Randrianarison, G., Ashraf, M. A. (2017): Microalgae: apotential plant for energy production. – Geology, Ecology, and Landscapes 1(2): 104-120.
[19] Sabiha, M. A., Saidur, R., Mekhilff, S. (2015): An experimental study on evacuated tube solar collector using nanofluids. – Transactions on Science and Technology 2(1): 42-49.
[20] Subramaniam, T. S., Kouvhner, B., Loguinov, V. (1998): Research of using solar energy curing flue-cured tobacco. – CORESTA 1998 (Agronomy and Plant pathologist). Zurich Switzerland.
[21] Tippayawong, N., Chutchawan, T., Satis, T. (2006): Investigation of lignite and firewood co-combustion in a furnace for tobacco curing application. – American Journal of Applied Sciences 3(3): 1775-1780.
[22] Truong, L. R., Raganit Jr, R. J., Cabigan, C. A., Cortero, O. D. (2016): Evaluation and modification of Anawang furace for Virginia tobacco. – Ilocos Journal of Science: 69.
[23] TSBCN (Technical specification for bulk curing barn China). (2009): Construction standard for bulk curing barn. – Chinese National Tobacco Corporation. http://www.doc88.com/p-03044266920.html.
[24] Verma, S. K., Tiwari, A. K. (2015): Progress of nanofluid application in solar collectors: A review. – Energy Conversion and Management 100: 324-346.

[25] Wang, X. F., Xu, G. Z., Zhang, B. L., Jiao, Y. Z., Lu, H. F., Li, B. M. (2015): Application of tobacco stems briquetting in tobacco flue-curing in rural area of China. – Int J Agric & Biol Eng 8(6): 84-88.

[26] Wu, H., Zhao, B., Gao, W. (2017): Distance indices calculating for two classes of dendrimer. – Geology, Ecology, and Landscapes, 1(2): 133-142.

[27] Xiao, X. D., Li, C. M., Ya, P., He, J., He, Y. S., Bi, X. T.(2015): Industrial experiments of biomass briquettes as fuels for bulk curing barns. – International Journal of Green Energy 12(11): 1061-1065.