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Australian Centre for International Agricultural Research

ADVANCING ENHANCED WOOD MANUFACTURING INDUSTRIES IN LAOS AND AUSTRALIA

Designing and building a solar kiln suitable for Vientiane's geography and climate, Laos

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22 June 2021

VALTIP 3

Acknowledgements:

Authors would like to thank to VALTIP3- ACIAR for providing a small grant to conduct this project. Thanks to VALTIP3 research fellows that contributed hands-on during the construction, Mr Khonethong Soukphaxay, Pongky Phommachanh, and Miss Sompatthana Tiemaliya. Thanks also to Mr Khanxay Khammanichan for his work on the technical drawings for a modified design of a solar kiln. Thanks to the final year students who provided their labor Mr. Khonexai Syvongsouk, Novice Pado Luangmany and Miss Fongsamouth Seesouk from the Department of Forest Economics and Wood Technology, Faculty of Forest Science, the National University of Laos. Thanks to many other people who provided their opinions on the construction processes on the solar kiln.

Citation: Phonetip, K. Boupha, L. Boupha, S and Khambouddaphan, S. (2021) Designing and building a solar kiln suitable for Vientiane's geography and climate , report produced for ACIAR project FST/2016/151 - Advancing enhanced wood manufacturing industries in Laos and Australia.

Contents

1. Introduction

The National University of Laos (NUoL) is the premier Lao tertiary educational institution, with the highest quality and quantity of teaching staff within the country. Within NUOL, the Faculty of Forest Science's (FFS) mission is to (a) organize teaching and training, (b) conduct scientific research, (c) provide academic services to society, and (d) conserve and promote traditional Lao culture, as well as selecting good culture and practices from other nations (FFS 2021). The FFS also provides capacity building for the wood industries sector through a demonstration wood technology center developed with support from ACIAR. Installing a solar kiln in this center was necessary for improving forestry education and research in Laos. The aim of this study was to develop a design for a solar kiln suitable for Vientiane's conditions, and build a demonstration kiln at the Faculty of Forest Science (FFS), the National University of Laos (NUoL).

There are various designs for solar kilns that can be used for drying timber that have been used in the timber industry for decades, including, for example, indirect and direct heat, and others as described by Satta (1993). Choosing the right design for a solar kiln based on product requirements and situational conditions will maximize productivity. The requirements may include affordability in construction, particularly in developing countries, and the structural design should be able to produce optimal drying productivity. Because the geographical conditions can affect drying time, with drying rate varying from one place to another (Hasan and Langrish 2014), consideration of locations specific conditions is essential.

The Government of Lao PDR has committed to reduce greenhouse gases (GHG) emission; in 19995 The Government ratified the UNFCCC and the Kyoto Protocol in 2003. It has developed a climate change strategy, which builds on the country's commitment to its climate change adaption efforts (UNDP 2018) and has prioritised green and sustainable development in its 9th Socio-Economic Development Plan to 2025. The wood processing sector contributes to GHG emissions by, amongst other activities, generating emissions through wood drying because, most kiln driers are steam kilns which use wood off cut as fuel (Redman 2016). Using wood fuel for energy could produce carbon emission up to 60% (Wibe 2012). Using solar kilns to dry wood is an alternative method that can be environmentally friendly by reducing the use of wood for fuel and economically beneficial because drying timber using a solar kiln is faster than air drying (Armstrong 1914), and when used in combination with steam a kiln can reduce costs (Phonetip et al. 2017).

Vientiane is the capital city of Laos, located in tropics with high solar radiation, conditions which are considered to be the most suitable location for solar kiln technology (Simpson and Tschernitz 1984). Phonetip et al. (2018) recently used GIS-based fuzzy method, to identify initial suitable locations and calendar months for running solar kiln in Vientiane, but also identified the need for site visits to confirm site suitability prior to installation. However, a specific suitable design for solar kilns for Vientiane does not exist. To develop such a design, a better understanding the Vientiane context and the geographical and climatic conditions in which solar kilns would operate is needed.

According to climatic data for Vientiane the temperatures reach 40^{o}C in summer (December until April) with the lowest relative humidity in in the range of 30-40% (SSE 2014). Using a conventional laboratory kiln as a simulation of a solar cyclic drying Phonetip et al. (2017) found that by using the lowest level of relative humidity (RH) of 40% and thus replicating the conditions in Vientiane, wood can dry 50% faster than at RH of 60%. This information is important for developing the requirement's for the suitable design of solar kilns for Vientiane.

2. Methods

Selection of a suitable solar kiln

Selection of a suitable design of a solar kiln was based on the method recommended by Visavale, G.L (2012). The selected prototype solar kiln was based a solar kiln located in Mumbai, India. Modifications to the design were made to reflect FFS requirement's and the climatic and geographical conditions for Vientiane as suggested by Phonetip et al. (2018), These are summarised in the table 2. The modified feature for drying cabinet and collector shown in table 1.

Table 1. Structural details by G. L. Visavale (2009) and proposed modifications

Drying cabinet		**Modified features**
Gross dimensions	1.12 × 0.76 × 0.40 m	2 x 1 x 1m
Spacing between two trays	0.025 m	0.02m and can be removal
Tray material	Al/ SS-316	Stainless steel
Tray Dimensions	0.56 x 0.76 x 0.025	No tray/ Flexible
Space between two trays	0.025 m	0.05
Tray type	mesh tray	Flexible
Number of trays	16	Flexible
Tray thickness	0.002 m	Flexible
Outlet pipe diameter	0.20 m	0.20 m
Mode of air flow	Forced convection	Forced convection
Air flow rate	1000 m3/h	1000 m3/h
Air velocity in cabinet	~1m/s	~3m/s (using knob fan speed)
Geographical Location	Mumbai, India. (18° 53"N & 72°50"E)	Vientiane, Laos. (18°02'29.5"N &102°37'51.9"E)
Collector		
Area of absorbing surface	20 m^2	9m^2
Number of absorbing surface	10	3 (3m x 1m)
Absorbing material	Black painted copper sheet	Black painted corrugated zinc
Insulation thickness	0.05 m	0.05 m
Insulation material	Plexifoam	Polyethelen foam coated by zinc
Transfer fluid	Air	Air
Collector tilt angle	25°, Facing south	39°, Facing south
Cover plate material	Glass	Clear plastic sheet
Dimensions of each panel	1 m x 2 m	0.9 x 3m
Absorber plate thickness	20 G	0.003m
Mode of air flow	Forced convection	Forced convection

3. Results

The results for the selection of a suitable design of a solar kiln for installing at the Faculty of Forest Science, the National University of Laos are shown in the table 2.

The Design

Following the proposed design from the table 1, a technical drawing for a kiln was created by Sketchup software (Figure 1). Construction of the kiln's body was undertaken byVALTIP3 research fellows at NUoL with support from final year students in FFS. All materials for the construction were sourced locally. The solar kiln was constructed and installed at the front of the Department of Forest Economics and Wood Technology at NUoL.

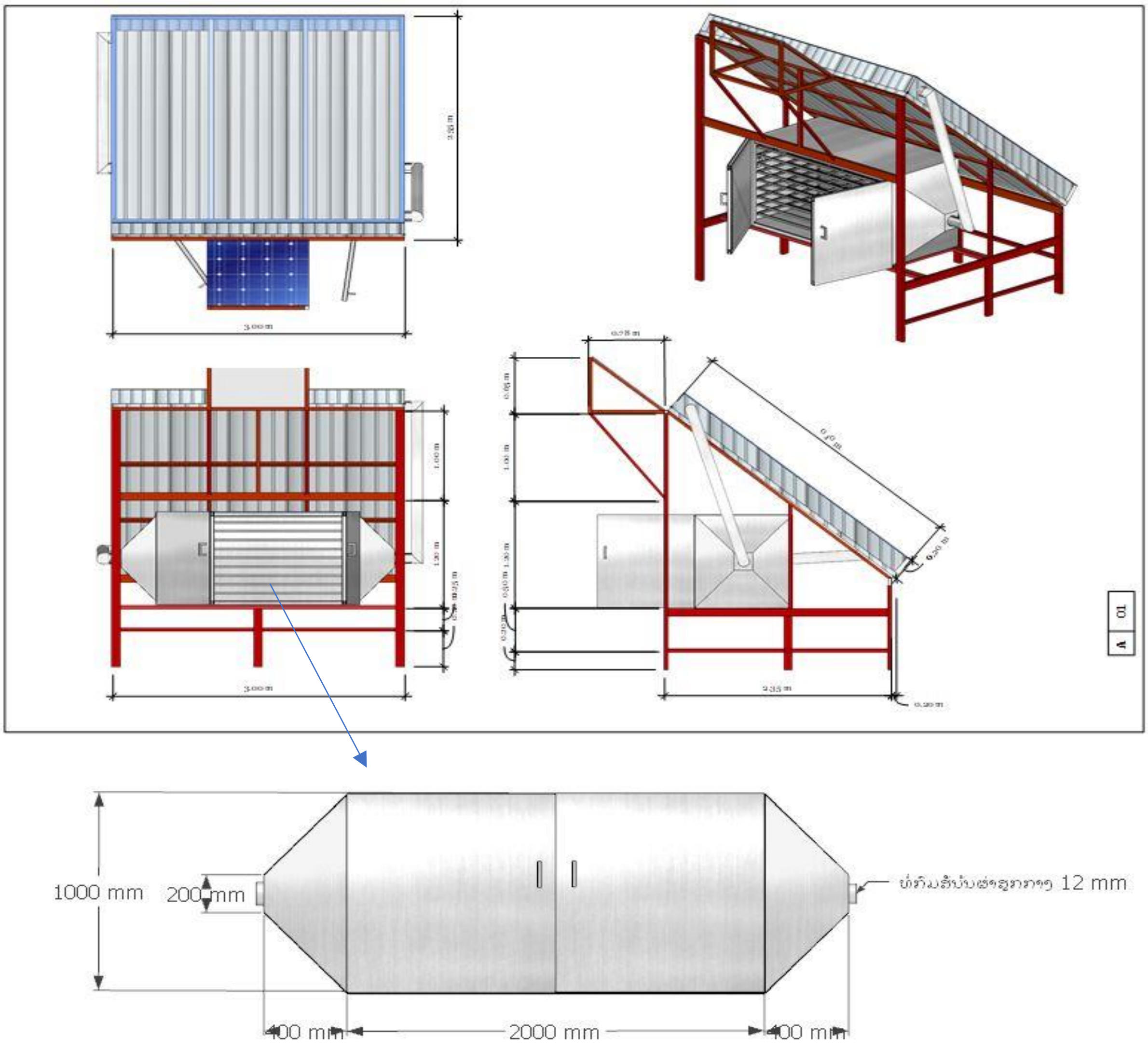

Figure 1. Component of a solar kiln design

Table 2. Principles, Classification and Selection of Solar Dryers based on Visavale, G.L (2012). The requirements are based on the researchers' perspectives of using the solar kiln as an experimental apparatus for the University plus some other scientific findings				
Parameters	**Feature**	**Requirements**	**Reasons and research findings**	**Comments/References**
Physical features of dryer	Type, size and shape	Solar Cabinet Dryer with (2 x 1 x 1)m	The Design was modified from Visavale, G.L., 2009. Small scale/Laboratory size. This design is considered that it is suitable for diversity of bio experiments. The number of trays can be flexible. However, the materials to be used would consider replaced by other available materials and affordable.	Visavale, G.L., 2009, Design and Characteristics of Industrial Drying Systems. Ph. D. thesis, Institute of Chemical Technology, Mumbai, India. The specification of size of the solar kiln was required by the Faculty of Forest Science (FFS, 2020)
	Collector area	3 x 3 m		
	Drying capacity/loading density (kg/unit tray area)	1.5m^3		
	Tray area and number of trays	20		
	Loading/unloading convenience	NA		
Thermal performance	Solar insolation	0.2-0.4Kw/m2/d	Based on Vientiane's geographical location and climatic conditions the solar kiln could reach a required level of temperature but a booster (heater) during raining season as per suggested by Phonetip et. al (2018)	Phonetip, K., Ozarska, B., Brodie, G., Belleville, B., and Boupha, L. (2018). "Applying a GIS-based fuzzy method to identify suitable locations for solar kilns," *BioRes.* 13(2), 2785-2799.
	Drying time/drying rate	NA		
	Dryer/drying efficiency	NA		
	Drying air temperature and relative humidity	Up to 50 C, lowest RH of 40%		
	Airflow rate	Up to 1m/s		
Properties of the material being handled	Physical characteristics (wet/dry)	Stainless steel to be used for structural frames, interior wall of kiln compartment and heat conducting tubes.	Using stainless steel could help with avoiding roasting due to Vientiane's geographical location is located in high humidity. For instance, the maximum relative humidity in Vientiane can be reached at 90%	This is required by the Faculty of Forest Science for long term use in teaching, learning and research purpose (FFS, 2020)
	Acidity	No harmful to human	All materials to be used as part of the solar kiln construction should	Further studies are suggested after the kiln has constructed.

	Corrosiveness	No harmful to human	not be harmful. After the kiln has been constructed. Assessing air quality within the kiln and a commodity after dried by a solar kiln will be conducted.	
	Toxicity	No harmful to human		
	Flammability	Polyethylene foam which is permitted with the temperature is less than 80°C	This material can be used as insulation for the collector. The polyethylene glued with the Alusing materials, which one side is a heat collector and another side is acted as insulation. Polyethylene foam which is permitted with the temperature is less than 80°C, this value obtained from our preliminary trials at the Faculty of Forest Science’s Laboratory (3 samples have been used in the trail with the mini heat press machine)	The technical sheet of this material is not available
	Particle size	NA		Not available
	Abrasiveness	NA		
Drying characteristics of the material	Type of moisture (bound, unbound, or both)	Both	Based on Vientiane's geographical location where EMC is calculated. The polyethylene foam cannot tolerate temperatures greater than 80C.	Phonetip, K., Ozarska, B., Brodie, G., Belleville, B., and Boupha, L. (2018). "Applying a GIS-based fuzzy method to identify suitable locations for solar kilns," BioRes. 13(2), 2785-2799.
	Initial moisture content	Green or partially dried		
	Final moisture content (maximum)	Can dry down to 7% of MC		
	Permissible drying temperature	Maximum of 80°C		Should be less than 80°C

Flow of material to and from the dryer	Quantity to be handled per hour	Based on type of drying objects	This is not applicable because the quality of drying or batch is varied depended on drying schedules and type of commodities	Not available
	Continuous or batch operation	Based on type of drying objects		
	Process prior to drying	Based on type of drying objects		
Product qualities	Shrinkage	Based on type of drying objects	The quality of drying products will be based on an interested commodity to be dried, so the quality will be initially assessed after the solar kiln has constructed and ready to be operated. A trail of a commodity will then assess the kiln capacity based on an existing suggested drying schedule, however, the commodity will be selected later on.	Not available, it is suggested that further study of this kiln performance should be conducted.
	Contamination	Based on type of drying objects		
	Uniformity of final moisture content	Based on type of drying objects		
	Decomposition of product	Based on type of drying objects		
	Over-drying	Based on type of drying objects		
	State of subdivision	Based on type of drying objects		
	Appearance	Based on type of drying objects		
	Flavour	Based on type of drying objects		
	Bulk density	Based on type of drying objects		
Recovery problems	Dust recovery	Sealed	The compartment is made by stainless steel with a clean and washable	Not available
	Solvent recovery	NA		
Facilities available at site of	Space	(4 x 4) m	The space should be considered as bigger than the collecting area (3m x 3m). As per suggestion by Phonetip et. al (2018). The designed	Phonetip, K., Ozarska, B., Brodie, G., Belleville, B., and Boupha, L. (2018). "Applying a GIS-based fuzzy
	Temperature, humidity, and cleanliness of air	50C		
	Available fuels	NA		

proposed installation	Available electric power	YES	level of temperature would need a booster (heater) during raining season. The relative humidity can be controlled based on programming for the solenoid. Using brushless fan can help to reduce the noise.	method to identify suitable locations for solar kilns," BioRes. 13(2), 2785-2799.
	Permissible noise, vibration, dust, or heat losses	Not higher than 80 Db		
	Source of wet feed	Solanoid controls mist		
	Exhaust-gas outlets	Exhaust fan		
Economics	Cost of dryer	Based on the physical feature of the dryer	The cost will be calculated based on all parameters	Not available
	Cost of drying	Based on type of drying objects		
	Payback	NA	The product is not for profit making but for research	
Other parameters	Skilled technician and operator requirements,	Training is required prior operating		Not available
	Safety and reliability	Training is required prior operating		
	Maintenance	Training is required prior operating		

The Solar Kiln

The Drying Unit

The kiln's drying compartment is where wood sample can be placed for drying and monitoring. The dimension is 1 x 1 x 2 m as shown in the Figures 2 and 3, with internal components shown in Figure 4 and 5.

Figure 2. Front view of a solar kiln

Figure 3. Side view of a solar kiln

Figure 4. Humidifier system

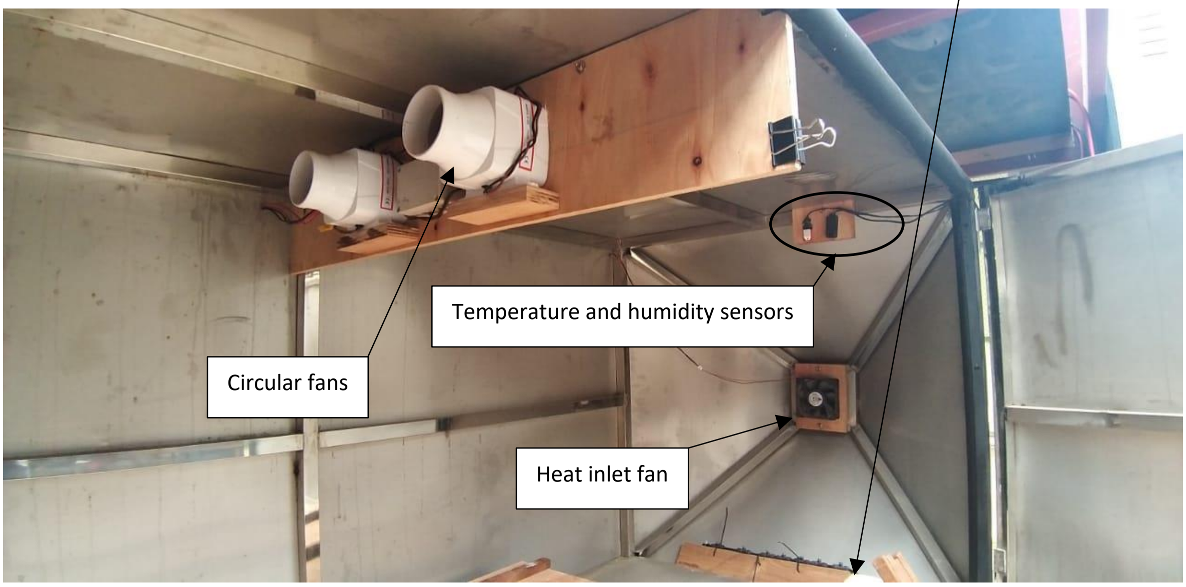

Figure 5. Inside the kiln compartment

Heat collector

The heat controller was built using materials of polyethylene foam insulated with zinc, with the outer part painted black. A transparent plastic sheet 0.1 μm thick was attached using spring wire clipping at the edges as shown in the Figure 6.

Figure 6. Heat collector

Controller system

The kiln controller, designed by Phonetip and has two parts: the solar power source and kiln controller units. The solar power unit consists of a solar panel of 200W (Figure 7), a solar charger with 30A, DC to AC converter (3000W) and a Battery of 95Ah (FB Battery, M-1700 (105D31-MF) as shown in the Figure 8.

Figure 7. Solar panel’s specification

The kiln controller unit consist of Aduino UNO boards with embedded codes to control two fans that suck heat from the heat collector, a circular fan that is installed inside the kiln's compartment, and a water pump for serving the relative humidity inside the kiln compartment. The Aduino UNO was shield by SD card module where the temperature and relative humidity data inside the kiln's compartment and heat collector are stored in the SD card.

Figure 8. Solar charger and Kiln controller unit

The data acquisition unit was controlled by an Arduino Uno with a sensor of DHT22 (temperature and relative humidity sensor). The accuracy of the DHT22 sensor, humidity is ±2 %RH (Max ± 5%RH) and temperature is <±0.5 Celsius (T Liu, 2021). The temperature and relative humidity have been recorded every 6 min and stored at SD card that shield with the Arduino Uno board. The RH was set and controlled by a water pump based on the setting value of reading by DHT22 for RH, the water pump is "Off" when the RH was indicated as higher than the set value and "On" mode when the RH was lower than the setting value. The temperature was also set and controlled by two inlet fans through heating induction pipe from heat collector. The fans are "On" mode until the temperature is reaching the setting value then stop "Off" mode when the temperature is higher or met the setting value. The sketch of coding was embedded in the Arduino Uno board using Arduino Integrated Development Environment (IDE) software. The code is available in Annex.

4. Conclusion and recommendation

The solar kiln design was based on a modified version of a previous design by G. L. Visavale (2012). The controller unit and solar power system have been designed and coded based on the requirements of the Faculty of Forest Science and also based on some parameters that suggested by research findings of Phonetip. The solar panels solar and charger unit were sourced locally from3S Company in Laos to generate power. The design of the solar kiln was found to be relatively straight forward and did not need a high level of engineering to install. The kiln's compartment was simple to construct but the controller unit requires specialist inputs and qualified electrical servicing. All materials were available in local Vientiane construction stores, providing for ease of replacement. Regarding the cost of the solar kiln, the most expensive parts were the controller unit and the kiln compartment. However, the kiln's compartment can use alternative materials like zinc rather than stainless steel which is more costly.

This full design, installation and operation was completed by experts and student at the FFS in Laos, but copyright has not been reserved. The FFS is happy for SMEs wood processors, for whom the kiln is likely most suitable, to take the design, build and use it.

It is recommended that the constructed solar kiln should be trialed to investigate its productivity performance outside the geographical and climatic conditions of the unit installed location of Vientiane and for different species of wood commonly processed in Laos. Trials in other locations in Laos, with different climate and geography would be needed to determine design modifications for optimal application.

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Annex 1: Code for controlling the temperature and relative humidity for a solar kiln

```
// Multi DHT22
// AUTHOR: Khamtan Phonetip
// Created date: 13 December 2020
// Purpose: Recording temperature and relative humidity from a minisolar kiln of the Faculty of Forest
        Sciences, the National University of Laos.
// Method of compiling sketch: Compiled from different sources
// Email: khamtanfof@gmail.com
// Mob: +856 20 2220 6926
#include <SD.h>
#include <Wire.h>
#include "RTClib.h"
#include <DHT.h>;
const int chipSelect = 10; //cs or the save select pin from the sd shield is connected to 10.
DS1307 RTC;
#define DHTPIN1 8
#define DHTPIN2 9
// Sensors No.1 and 2 are used to measure the data from two different sources
//DHTPIN1 measures inside the solar kiln's compartment
//DHTPIN2 measures inside the heat collector of the solar kiln
DHT dht[] = {
  {DHTPIN1, DHT22},
  {DHTPIN2, DHT22},
};
float humidity[2];
float temperature[2];
File dataFile;
DateTime now;
void setup()
{
  Serial.begin(57600);
  for (auto& sensor : dht) {
    sensor.begin();
```

```
}

//setup clock
Wire.begin();
RTC.begin();
//check or the Real Time Clock is on
if (! RTC.isrunning()) {
  Serial.println("RTC is NOT running!");
  // following line sets the RTC to the date & time this sketch was compiled
  // uncomment it & upload to set the time, date and start run the RTC!
  //RTC.adjust(DateTime(__DATE__, __TIME__));
}
//setup SD card
Serial.print("Initializing SD card...");
// see if the SD card is present and can be initialized:
if (!SD.begin(chipSelect)) {
  Serial.println("Card failed, or not present");
  // don't do anything more:
  return;
}
Serial.println("card initialized.");
//write down the date (year / month / day     prints only the start, so if the logger runs for sevenal
      days you only findt the start back at the begin.
now = RTC.now();
dataFile = SD.open("datalog.csv", FILE_WRITE);
dataFile.print("Start logging on: ");
dataFile.print(now.year(), DEC);
dataFile.print('/');
dataFile.print(now.month(), DEC);
dataFile.print('/');
dataFile.print(now.day(), DEC);
dataFile.print(',');
dataFile.print(now.hour(), DEC);
dataFile.print(":");
```

```
  dataFile.print(now.minute(), DEC);
  dataFile.print(":");
  dataFile.print(now.second(), DEC);
  dataFile.println("          ");
  dataFile.println("Date, Time, Tk(C), RHk(%), Tc(C), RHc(%)"); //Tk and RHk is the condition
        inside the solar kiln compartment, and Tc and RHc are the conditions inside the heat collector
        area
  dataFile.close();
}
void loop()
{
  for (int i = 0; i < 2; i++) {
    temperature[i] = dht[i].readTemperature();
    humidity[i] = dht[i].readHumidity();
  }
  for (int i = 0; i < 2; i++) {
    Serial.print(" T:");
    Serial.print(temperature[i]);
    Serial.print(',');
    Serial.print(" RH: ");
    Serial.print(humidity[i]);
  }
  //read the time
  //RTC.adjust(DateTime(__DATE__, __TIME__));
  now = RTC.now();
    //open file to log data in.
  dataFile = SD.open("datalog.csv", FILE_WRITE);

  // if the file is available, write to it:
  // log the temperature, humidity and time.
  if (dataFile) {
    for (int i = 0; i < 2; i++) {
      temperature[i] = dht[i].readTemperature();
      humidity[i] = dht[i].readHumidity();
```

```
    }
    for (int i = 0; i < 2; i++) {

      dataFile.print(now.year(), DEC);
      dataFile.print('/');
      dataFile.print(now.month(), DEC);
      dataFile.print('/');
      dataFile.print(now.day(), DEC);
      dataFile.print(',');
      dataFile.print(now.hour(), DEC);
      dataFile.print(":");
      dataFile.print(now.minute(), DEC);
      dataFile.print(":");
      dataFile.print(now.second(), DEC);
      dataFile.print(',');
      dataFile.print(temperature[0]);
      dataFile.print(',');
      dataFile.print(humidity[0]);
      dataFile.print(',');
      dataFile.print(temperature[i < 2]);
      dataFile.print(',');
      dataFile.print(humidity[i < 2]);
      dataFile.println("                ");
      dataFile.close();
    }
    Serial.println(" >>> data stored in SD Card");
  }
  // if the file isn't open, pop up an error:
  else {
    Serial.println("error opening datalog.csv");
  }
  delay(360000); // this will log the temperature and humidity every 6 minutes (360000ms).
}
// END OF FILE
```