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Hydro-Thermal Assessment of a Vegetable Cool Room under Natural Cooling Condition

Mohammed A., *Saleh, A. and Dalha I.B.

[1]*Department of Agricultural Engineering, Ahmadu Bello University-Zaria, Nigeria*

Corresponding Author: salehaminu@gmail.com (+234803 577 4780)*

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Abstract: *Cold storage is one of the methods used in preserving the quality of fruits and vegetables. Farmers often sundry their vegetables and store them under ambient condition at home rooms and market stalls for out of season markets. At the end of the storage, the products quality deteriorate as such attracts low value. A vegetable cool room was designed and constructed using stabilized rammed earth blocks in cavity wall form and insulated with thatch materials, at the Department of Agricultural and Bio-resources Engineering, Ahmadu Bello University, Zaria. The cool room was powered by natural cooling through trees shading. Temperature and humidity of the room was evaluated before loading the vegetables. Temperature and humidity mappings at no load condition were also carried out on the room walls, floor, and roof as well as room air space according to international standards via digital temperature and humidity sensors. Readings were taken at 5 hr intervals starting from 5 am throughout the day. At 5 am, Wall1, Wall2 and Wall3 gave a minimum outside temperature of 13.2°C, 14°C and 15°C with an average corresponding inside temperatures of 24°C. At upper day time of 2.00 pm, Wall1 had the highest outside temperature of 40.2°C with corresponding inside temperature of 27°C. The room door had outside temperature of 39°C and inside of 28.4°C, the mean room space temperature was 24°C. The room relative humidity turns to be higher towards the floor with value of 44% in which the day environmental humidity was 35.9%. At all levels of the inside temperature fluctuates around 25°C that falls within the acceptable range of storing dried fruits, while the relative humidity of the room increases with increase in ambient relative humidity.*

Keywords: *Cool room, Laterite block, Thatch, Insulation, Temperature and Relative humidity*

INTRODUCTION

Vegetables are important protective food for the maintenance of health and prevention of diseases (Ajieroh, 2021). The production of vegetables has been recognized as the most affordable and accessible sources of micronutrients to millions of Nigerians. Vegetables value addition is increasingly regarded as a catalyst for rural development and as a means of increasing and generating foreign exchange in Nigeria (Kumar *et al.*, 2010). Both leafy and non-leafy vegetables are produced, within which 20-45% of the production are lost annually along the post-harvest chain, despite the national consumption demand has not been met (FAO, 2016). During market glut or low prices, farmers resolved to sun drying the vegetable and storing them for out of season higher prices.

Many undesirable quality changes occur in the dried vegetable products during storage (Maskan, 2000; Maskan, 2001). One of that is the colour of products which is an important quality index concerning consumer acceptance (Dermesonlouoglou *et al.,* 2007; De Sousa *et al.,* 2008). Deterioration mechanisms in dried foods that affect its quality are usually assumed to be dependent on these parameters: time, temperature, oxygen, light and moisture. In northern Nigeria, the storage period of the dried vegetables was from March to August, this turn to be a high temperature and humidity period (Saleh and Jamiu, 2022) and finally affect the quality of the vegetable while in storage.

To remedy the above situation, a vegetable cool storage that will work under natural cooling provided by trees using locally available construction materials was designed and constructed at the Department of Agricultural and Bio-Resources Engineering of the Ahmadu Bello University, Zaria. Hydro- Thermal assessment was conducted in the store in terms of heat flow and moisture flow in order to ascertain the performance of the natural cooling system applied.

MATERIALS AND METHODS

2.1 Materials

The project site was at the Research Reserve Field of the Department of Agricultural and Bio-Resources Engineering, Ahmadu Bello University, Samaru –Zaria, Kaduna State-Nigeria with latitude 12° 12'N, longitude 07˚ 37'E at 550 m altitude (Adeyemi *et al.,* 2019). A dried vegetable proto-type cool room was designed and constructed using stabilized laterite soil and cement mixed to produce bricks (at a ratio of 94:6 %) rammed earth blocks (230 x 110 x 100 mm), insulated with thatch materials harvested from the University farm. Also, a cavity wall design and adopted as walling material (cavity type walls) as suggested by Adriana (2009). The specification of the room was 2000 x 1500 x 2325 mm. Infra-red thermometer Fluke 62(0-750^{o}C/0.1^{o}C), relative humidity meter Smart Sensor AR337(10-99%/±3%), and excel worksheet (2.0) were used as instrumentation materials during the work.

2.2 Methods

The construction of the cool room (Plate1) and hydro-thermal environmental measurements were conducted according to Sukai, (2008). It was based on several tests at variable rate interval, applied to a refrigeration system as an eco-sustainable technology transfer alternative that is intended to be achieved from ambient temperatures of 30°C to -2°C. The stresses caused by temperature variation between the inner and outer facing walls were also considerable and vary depending on the location of the cool room by adequate bonding of the materials. The room's walls labeled 1, 2, and 3 were gridded into 20 x 20 cm both inside and outside including roofs and floors; a total of 48 grids were marked on the longer walls while 30 were marked on the shorter walls, floor and roof (WHO, 2014). Center point temperature of each grid was measured using a calibrated infra-red digital thermometer. The measurement was repeated at 5hrs interval within a day starting from 5am; ambient temperatures and corresponding relative humidifies were also measured. The air space inside the room was divided into three layers, space towards the roof, mid-room space and space towards the floor and gridded as above. Temperatures and relative humidity of the room air were measured at the three levels. The data generated was documented and analyzed using descriptive statistic via Statistical Analysis System (SAS).

Plate1 Pictorial view of the constructed cool rooms indicating the applied natural cooling

RESULTS AND DISCUSSION

The cool room has been designed and constructed as an alternative of improving efficiency and starting with the path of sustainability and use of indigenous resources with the aim of decreasing environmental impacts as suggested by Gámez *et al.* (2019). In the design and construction of the cooling system, different materials and equipment have been used that will allow it to materialize as an industrial and commercial conditioning system already in operation. Results obtained from the study shows that at 5.00 am Wall2 showed a minimum outside temperature of 13.2^{o}C which was the least among the remaining walls (Table1), but the corresponding inside room temperature of the same wall was 24^{o}C. This wall was facing eastern direction which was the direction of flow of monsoon wind of the season. Wall1, wall3 were the closest in cooling with 14^{o}C and 15^{o}c, at the same time their corresponding inside room temperature fluctuate around 24^{o}C despite the outside cold temperatures. Similar experiments were conducted by Deboucha and Hashim (2010) with the AC set at the storage temperatures, time to reach the set temperature and air throw were also measured with relatively similar results obtained.

Table-1 Room 1 wall temperatures (˚C) at 5.00 am

5.00am		N	Temperature		Sum	Mean	Std Dev	Variance
			Minimum	Maximum				
Wall1	Inside	48	24.20	26.60	1217.00	25.3542	0.60948	0.371
	Outside	48	14.80	18.20	783.20	16.3167	0.78370	0.614
Wall2	Inside	48	23.60	26.00	1192.80	24.8500	0.59430	0.353
	Outside	48	13.20	17.20	724.80	15.1000	0.80741	0.652
Wall3	Inside	48	24.20	25.44	372.60	24.6250	0.56519	0.650
	Outside	48	14.80	15.60	799.80	15.7458	0.24807	0.684
Roof	Inside	48	24.40	25.60	1194.50	24.8854	0.30387	0.092
	Outside	48	20.60	26.80	1244.40	25.9250	0.86011	0.740
Door	Inside	20	22.80	23.80	466.80	23.3400	0.26036	0.068
	Outside	20	15.60	18.60	330.60	16.5300	1.08244	1.172
Floor	Inside	48	20.60	26.80	1244.40	25.9250	0.86011	0.740

Environmental temp = 18.9^{o}C, RH = 39.3%

Looking at wall temperatures at 2.00 pm (Table-2), Wall1 had the maximum outside temperature of 40.2°C with corresponding inside of 27°c. The door outside temperature of 39°C follows with its corresponding inside temperature of 28.4°C. However, looking at the mean temperatures from Table 2 it could be seen that the inside wall temperatures fluctuate around same 25°C. Storage temperature of 25°C were also obtained by Bilge *et al*. (2012) and Md and Klaus (2009) and set on the air conditioner in each room accordingly and closed for experimentation. However, each of these vegetables was prepared according to farmer storage method and used as control. The remaining times of 12.00 mid night and 10.00 am indicated same mean inside wall temperature pattern (Tables-3 and 4). At this juncture we could say that whether the outside wall temperature is hot or cold, the mean inside wall temperatures remains around 25°C. This room was 75% shaded by a tree (natural cooling). Hydro-thermal environmental measurements were conducted on the rooms by Ogunlowo (1999) and Sukai, (2008) and obtained similar results with this study. Md and Klaus (2009) also investigated the effect of storage temperature and observed that all the quality indicators significantly decrease at higher temperature and moisture content, while no significant difference were recorded at low temperature and low moisture content.

Table-2 Room 1 wall temperatures (°C) at 2.00 pm

2.00pm		N	Temperature		Sum	Mean	Std Dev	Variance
			Minimum	Maximum				
Wall1	Inside	48	24.80	27.20	1231.40	25.6542	0.62670	0.393
	Outside	48	27.00	40.20	1523.20	31.7333	4.15002	17.223
Wall2	Inside	48	24.20	26.80	1198.80	24.9750	0.64131	0.411
	Outside	48	25.20	30.40	1308.10	27.2521	0.93217	0.869
Wall3	Inside	48	24.20	25.80	1210.40	25.2167	0.48084	0.231
	Outside	48	24.40	28.40	1228.80	25.6000	0.76742	0.589
Roof	Inside	48	24.60	26.60	1212.20	25.2542	0.36376	0.132
Door	Inside	32	27.80	28.40	900.40	28.1375	0.12636	0.016
	Outside	32	30.00	39.00	1062.20	33.1937	2.21169	4.892
Floor	Inside	48	22.60	27.40	1268.90	26.4354	0.68773	0.473

Environmental temp. = 28.4°C, RH = 26.1%

Table-3 Room 1 wall temperatures (°C) at 10 am

9.00am		N	Temperature		Sum	Mean	Std Dev	Variance
			Minimum	Maximum				
Wall1	Inside	48	24.60	27.20	1234.80	25.7250	0.67114	0.450
	Outside	48	18.40	28.20	1082.80	22.5583	2.90677	8.449
Wall2	Inside	48	23.80	28.80	1230.40	25.6333	0.81927	0.671
	Outside	48	17.20	28.00	1016.00	21.1667	3.21627	10.344
Wall3	Inside	48	24.80	26.40	1234.60	25.7208	0.39083	0.153
	Outside	48	17.20	20.40	906.40	18.8833	0.69139	0.478
Roof	Inside	48	24.30	25.20	1182.70	24.6396	0.20498	0.042
Door	Inside	20	24.60	24.80	492.60	24.6300	0.07327	0.005
	Outside	20	20.60	20.80	414.10	20.7050	0.09987	0.010
Floor	Inside	48	20.20	27.40	1263.48	26.3225	0.99443	0.989

Environmental temp. = 20.9°C, RH = 35.9%

Table-4 Room 1 wall temperatures (°C) at 12.00 mid night

12.00mid night		N	Temperature		Sum	Mean	Std Dev	Variance
			Minimum	Maximum				
Wall1	Inside	48	25.20	27.20	1252.60	26.0958	0.56265	0.317
	Outside	48	17.80	20.40	904.40	18.8417	0.70253	0.494
Wall2	Inside	48	20.20	26.80	1234.00	25.7083	0.91880	0.844
	Outside	48	16.80	20.00	886.30	18.4646	0.79319	0.629
Wall3	Inside	48	25.20	26.20	1235.40	25.7375	0.28029	0.079
	Outside	48	17.80	20.40	908.50	18.9271	0.61670	0.380
Roof	Inside	48	25.20	25.80	1226.40	25.5500	0.20000	0.040
Door	Inside	20	23.00	25.20	488.00	24.4000	0.44010	0.194
	Outside	20	18.00	19.60	372.20	18.6100	0.52103	0.271
Floor	Inside	48	25.40	27.20	1263.80	26.3292	0.49248	0.243

Environmental temp. = 20.3°C, RH = 37.5%

Furthermore, the mean room space air temperature stands at 24°C while the maximum air temperature fluctuates around 25° C (Table-5). Within the same space the mean air relative humidity was 44% and it was maximum towards the roof at 49.9% (Table 6). It was observed that the relative humidity is closely proportional to the temperatures generated, the higher the temperature, the lower the humidity. Storage temperature of 25°C were also obtained by Bilge *et al.* (2012) and Md and Klaus (2009) thus agreeing with the findings of this study. In a study by García and Pacheco (2007), two types of vegetables were stored at a temperature of 24°C, obtaining results of non-susceptibility to cold, maintaining the physical characteristics for 5 days.

Table-5 Room inside space temperature (°C) at 10.00 am

	N	Temperature		Sum	Mean	Std Dev	Variance
		Minimum	Maximum				
Towards Roof	30	22.20	24.50	717.90	23.9300	0.53185	0.283
Middle	48	24.40	25.20	1183.90	24.6646	0.19731	0.039
Towards Floor	30	24.50	24.80	739.30	24.6433	0.08584	0.007

Table-6 Room Relative Humidity (%) at 10.00 am

	N	Temperature		Sum	Mean	Std Dev	Variance
		Minimum	Maximum				
Towards Roof	30	41.20	49.90	1298.50	43.2833	2.18065	4.755
Middle	30	41.30	45.00	1317.40	43.9133	0.96481	0.931
Towards Floor	30	42.20	45.90	1322.50	44.0833	0.74189	0.550

Environmental temp. 20°C and RH, 35.9%

CONTRIBUTION TO KNOWLEDGE

This study has established a system of vegetable storage using locally available insulation materials at controlled temperatures to in order to reduce wastages incurred by farmers and merchants. This would as well add value of the produced for increased income.

CONCLUSION

The hydro-thermal assessment in a cool storage system is conducted for the purpose of ascertaining the performance of the cool storage system which can allow selection of the type of vegetables to be applied in the storage. Temperature measurements of the room indicated that the mean inside room temperatures (walls and space) of the room at natural cooling revolved around 25^{o}C irrespective of the value of outside temperature. The inside room relative humidity increases as the environmental relative humidity increase. The mean environmental temperatures during summer in Nigeria is a little above 40^{o}C, since the inside room temperature remained around 25^{o}C at environmental temperature of 41^{o}C. Farmers are seldom free to store both leafy and non- leafy vegetables for their marketing activities.

CONFLICT OF INTEREST

The authors declare no competing interest

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