Estimation of Service Life for a Solar Chimney-Collector System

A. A. Adedej, J. O. Aweda and O. A. Lasode

Abstract **- The use of a solar chimney-collector enhances natural ventilation and passive cooling strategies of buildings thus helps in reducing energy use, CO_2 emission and pollution in general. The aim of this paper was to obtain a service life of a solar chimney-collector gadget attached to a specimen room to realise a natural ventilation. The room was made of glass which conditioned it to a remarkable heat, while the solar chimney comprised of insulated wooden box, a vent pipe and an inlet opening with its cover made of the solar collector (a flat box of photovoltaic glass cap, optical coated aluminium absorber and serpentine tube). Results of a five week internal microclimatic condition measurement each, for solar chimney and the specimen room with all windows opened and all windows closed, show that a test-retest reliability analysis of 0.745 and 0.711 were obtained respectively, while at the average life-time failure probability of 0.266, the chimney-collector system will serve for 50 years.**

Index Terms **- Energy, solar collector, chimney, reliability, service life.**

1. Introduction

One of the major steps in improving indoor air quality is pollutant removal. This involves increased volumes of, and more controllable, ventilation as well as porous adsorbers. Though hygroscopic materials can moderate relative humidity and can permanently absorb some volatile organic compounds [1], a combination of an airtight building enclosure and quality filtration of ventilation air, by mechanical or natural means can be used to greatly reduce the number of particulates.

Reliability estimators are categorised into four by [2] These are: (i) Inter-Rater reliability which is used to assess the degree to which different raters give consistent estimates of the same phenomenon, (ii)Parallel-Forms reliability is the assessment of the consistency of the results of two tests constructed in the same way from the same content domain, (iii) Internal Consistency reliability used to assess the consistency of results across items within a test and (iv) Test-Retest, used in this work, Reliability in which the consistency of a measure from one time to another is assessed .

In order to construct and find the service life time analysis of a solar chimney-collector used for enhancing ventilation in a room, the following objectives were put in place:

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- data were obtained for materials and their properties for the construction of the solar chimney-collector.
- specimen model room was constructed and the solar chimney-collector was attached to the model room.
- the internal microclimatic condition of the specimen

room was evaluated by measuring the temperatures of both the solar chimney-collector and the room at a regular interval of time.

II Use of Solar Chimney-Collector

A. Advantages

The use of a solar chimney may benefit natural ventilation and passive cooling strategies of buildings thus help reduce energy use, CO_2 emissions and pollution in general.

Potential benefits regarding natural ventilation and use of solar chimneys include [3] :

- Improved ventilation rates on still, hot days
- Reduced reliance on wind and wind driven ventilation
- Improved control of air flow though a building
- Greater choice of air intake (i.e. leeward side of building)
- Improved air quality and reduced noise levels in urban areas
- Increased night time ventilation rates
- Allow ventilation of narrow, small spaces with minimal exposure to external elements
- Improved passive cooling during warm season (mostly on still, hot days)
- Enhanced performance of thermal mass.
- Improved thermal comfort (improved air flow control, reduced draughts)
- It requires no major maintenance once it is installed.

B Limitations

- Lower magnitude compared to wind ventilation
- Relies on temperature differences (inside/outside)
- Design restrictions (height, location of apertures) and may incur extra costs (ventilator stacks, taller spaces)
- The quality of air it introduces in buildings may be polluted in urban or industrial areas

III Methodology

The various major building materials used for the construction of the model building specimen with the solar chimney include: pyrex glass (used for the model building specimen), aluminum roofing sheet, ply wood (used as an insulator), transparent glass, aluminium metal sheet (coated black) and the pipe (used as air outlet). Also the major tools used during the construction of the model building specimen include: Chloroform, Araldite (both were used mainly as adhesive materials). Fig. 1 shows the section of a solar collector while Table 1 presents the materials properties

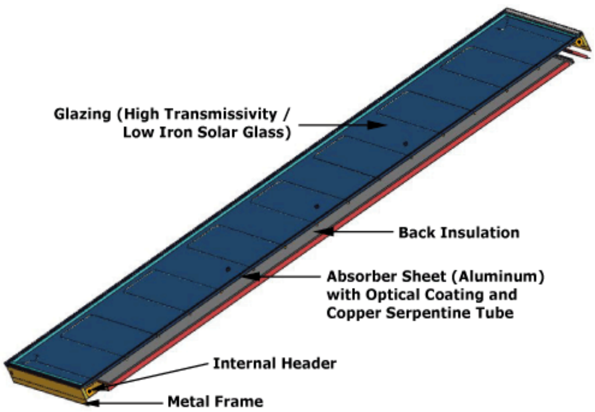

Figure 1 Solar collector

The absorber (Aluminium) is fixed in the same frame and directly below the plain glass. The absorber is coated in black.

Table 1 Properties of plain glass and absorber

Materials	**Specific heat (kj/kg°c)**	**Density (kg/m³)**	**Reflecti-vity**	**Absorbti-vity**
Glass (Plain glass)	1.1	2200	0.9	-
Aluminium (absorber)	0.88	2.700	-	0.78

Source: Olayioye [3]

The model room installed with the solar chimney collector is shown in Fig. 2 while Fig. 3 highlights solar chimney attached with the building.

Fig. 2 Chimney-collector attached to the room

Fig. 3 Solar chimney attached with the building

IV TEMPERATURE MEASUREMENT

The average temperatures, using digital multimeters (Fig. 4) were used for the ambient, room, chimney for the two conditions (i.e. for window closed & window opened) between for 5 weeks, between 10.00 Hrs to 15.00 Hrs each day. The average results are shown respectively in Fig. 5.

Figure 4 Digitam multi-meter

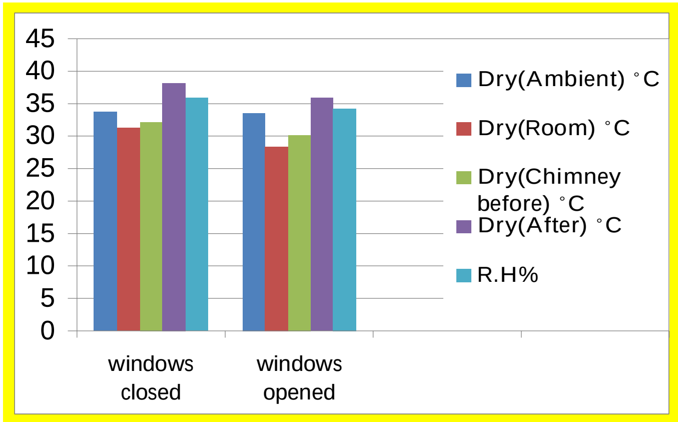

Fig. 5 Average values of the ambient, room and chimney temperatures and the Relative Humidity (%) for the rooms' closed and opened windows

V RELIABILITY TECHNIQUES AND APPLICATION

Constant failure rate (CFR) is employed here for easy algebraic manipulation [4, 5].

$$R(t) = e^{-dt} \tag{1}$$

where R(t) = total temperature in a week, $d_i = \frac{T_{Av(i)}}{R_{I-1}}$ is ratio of average temperature to total temperature and t = time (week), and T_{av}= average temperature. The failure density is expressed with respect to constant rate of failure as:

$$F(t) = de^{-dt} \tag{2}$$

So that the estimator is expressed as recommended by Leitch [4]:

$$F(t) = 1\text{-}e^{-dt} \tag{3}$$

The mean time to failure (MTTF) is the average functioning (without a failure) period for an item or average life cycle of a number of items, is expressed as:

$$MTTF = 1/d \tag{4}$$

So that reliability :

$$R = e^{-t/m} \tag{5}$$

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where t = period of time, d = temperature intensity/week, m = expected average numbers of break down = 2 (assuming that all other parts of the solar collector remain stable except glass and black painted aluminium that may break due to a dynamic force and colour faint respectively). Average temperature intensity/week, for room with window closed only, is shown in Table 2.

Table 2 Average temperature /week (window closed)

Week	**Average temper-ature (T_{av}) °C**		**Energy (Q) W**		**Temper-ature intensity (R_i) %**		**Rate per week (d)**	
	RT	**CT**	**R**	**C**	**R**	**C**	**R**	**C**
1	32	37	92.93	98.56	51.1	20	0.63	1.86
2	33	40	118.27	76.03	61.0	18.5	0.54	2.16
3	32	34	185.86	25.34	55.9	13.2	0.57	2.57
4	34	41	123.90	38.11	36.7	10.2	0.92	3.9
5	32	36	98.56	74.62	37.0	12.0	0.86	3.00

RT, **C**T = **R**oom and **C**himney temperatures respectively

Optimum design based on service life cost

Minimum material cost may not be the most essential characteristics for the utility of a structural component. If failure consequence is taken into account, the general criteria for the design of the solar chimney-collector produce the minimum total expected cost were considered here: (a) initial expected cost $\mathbf{C_i(t)}$ and (b) expected failure during life-time (cost due to damage of collector glass and colour faint on aluminium) This is necessary to introduce lifetime failure probability P_{life} in the objective function which is minimized as,

$$C_{life.min} = C_i\,(t) + C_{cf} = C_i\,(t) + C_f P_{life} \quad (6)$$

In which: $$P_{life} = 1 - \phi\,(R(t)) \quad (7)$$

and $$C_f = 1.0C_m \quad (8)$$

where $\mathbf{C_m}$ = cost of materials which are damage (glass) and colour faint (black soot on aluminium) during the service life of the solar chimney-collector is ₦300.00 (year 2009).

VI Results of Analysis and Discussion

A Cost analysis

The cost of constructing a standard room size of 3.6m x 3.6m x 3.0m, using Pyrex glass for the building wall with the solar chimney-collector, is about ₦373,598.00, and when the cost was projected for the same room size using sandcrete blocks with a solar chimney-collector attached to it, the cost of construction is ₦2, 213,127.00 (in June, 2009).

B Reliability analysis

Results of the analysis showed that:, for a closed window room, the MTTF of 0.303, the average Reliability = 0.746, while the reliability of 0.711 was recorded for a room with window opened with lifetime failure probability P_{life} = 0.288. At the reliability of 0.746 for P_{life} = 0.254, service life of the solar chimney-collector is estimated to be 50yrs.

VII Conclusion

From the measurement of the room temperature, it was observed that the relative humidity levels in the air changes drastically through the heating and cooling processes. These processes lead to extreme wide variation of the relative humidity levels indoors. The relative humidity range, 32-37%, in a room complies with requirement by the Environmental Protection Agency [6, 7] of 30–50% whereby validating the results of this work.

The solar chimney works well even when the window is closed. The service age of 50years gives a reliability of 0.711 for the chimney-collector unit service life.

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