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Effect of ventilation opening levels on thermal comfort status of both animal and husbandman in a naturally ventilated rabbit occupied building

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A b s t r a c t. Three levels of ventilation openings (100, 30, and 50%) of inlet were considered in this study under a natural ventilation method for rabbit production. The study was conducted using a model animal building. The external and internal temperature and relative humidity were measured over the experimental period. The measure of thermal comfort within a locality was hence determined by temperature humidity index (THI) for both animal and husbandman while relative strain index (RSI) was also considered for man.

The results showed that the amount of ventilation opening and building orientation have significant effects on the thermal comfort level of a building as indicated by the THI levels at 1% level of significance for both rabbit and man, which is also the same for the RSI for man. The larger the inlet opening and closer to perpendicular to the prevailing wind is the opening the higher is the thermal comfort level for both man and animal as seen in the values of THI for both rabbit and man and the RSI value for man in the case of 50% ventilation opening pens of the 90° orientation building. This may be attributed to the larger quantity of air passing through the building with increasing opening ratio. This affects the amount of heat and moisture that is removed from the building, hence the level of both temperature and relative humidity resulting in a more comfortable building internal environment for both animal and husbandman.

K e y w o r d s: building orientation, micro-environment, opening effectiveness, thermal comfort, ventilation

INTRODUCTION

The desirability of positioning buildings with respect to the direction of prevailing winds and earth-sun angular relationship cannot be over-emphasized, as it is known that weather has a major influence on agricultural production and other related processes. The primary purpose of building openings and orientation is to control heat and moisture concentration of the building air within a prescribed limit, employing natural ventilation (Duncan *et al*., 1981). Successful environmental modification is achieved when a structure enhances the thermal environment to maximize production whether for animal or the husbandman (Bosco *et al*., 2002; Diesch and Froehlich, 1988). Those authors further stated that the animal growth conditions, predictable within a livestock structure, depend much on the external and internal environmental conditions surrounding the structure.

In order for an organism to be comfortable in a given environment over a long period of time energy gained must equal energy lost (Bird *et al*., 1960). The thermal environment, the temperature, humidity and airflow balanced with occupants' heat and moisture productions are part of the total environment. According to Lokhorst *et al*. (1995) this thermal environment is mostly considered under the environmental control of the major critical factors of temperature, humidity and air movement. They also went further to state that the air circulation pattern (ventilation) has a dominating influence on the air mixture, temperature and humidity gradients. Hence, environmental modification for thermal comfort inside a building is then a function of airflow pattern which will depend on ventilation apparatus (amount of inlet opening; outlet opening, configuration of opening, obstacle, *etc*.) and various factors influencing airflow (air speed at inlet, temperature and humidity of incoming air, occupants' heat and moisture production level) and building parameters (heat transfer through building materials, equipment, orientation), (Boutet, 1987; Grool Koerkamp, 1998; Lokhorst *et al*., 1995; Ogunjimi *et al*., 2007). Airflow

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rate, according to Markus and Morris (1980), Esmay and Dixon (1986), Barrington *et al.* (1992), Nääs *et al*. (1998), is given by the equation:

$$Q = E\,A\,v, \qquad (1)$$

where: Q is air flow rate ($m^3\ s^{-1}$), A is area of inlet (m^2), v is wind velocity ($m\ s^{-1}$) and E is the opening effectiveness which, according to Nääs *et al.* (1998), directly affects the amount of airflow and is highly influenced by the difference between the inlet and outlet openings proportion. The opening effectiveness, E, is given by:

$$E = 16.33\left[\frac{0.2l\rho v}{\mu}\right]^{-0.3515}\left[Sin\left(\phi\right)\right]^{1.201}\left[\frac{4h}{l}\right]^{-0.1213}\left[Sin\left(\theta\right)\right]^{-0.1531}, \qquad (2)$$

where: ρ is air density ($kg\ m^{-3}$) - 1.21 $kg\ m^{-3}$ at 22°C, v the air velocity ($m\ s^{-1}$); μ the absolute air velocity ($Ns\ m^{-2}$) – 0.0000182 $Ns\ m^{-2}$ at 22°C, ϕ and θ are the wind angle of incidence (20 to 90°) and the roof slope (10 to 30°), respectively, $h\ 1^{-1}$ is the ratio of height to length of the inlet opening (1/4 to 1/8).

Animals – like man – are homeothermic, that is, they maintain a relatively constant deep body temperature that varies only slightly while surrounded by a variable external environment. However, under very stressing conditions, among which heat stress is very prominent (Esmay and Dixon, 1986; Habeeb *et al*., 1992), heat stress is built up jointly by the ambient temperature and relative humidity in particular. During such conditions of stress, animals, in order to keep within the temperature range, must reduce their internal heat production, enhance their heat dissipation mechanism or combine both (Egbunike, 1979; Habeeb *et al*., 1992; LPHSI, 1990). For efficient performance, livestock should be under a condition that limits the fluctuations in environmental factors of production within the thermoneutral zone where the required environment for efficient production is maintained throughout the production period.

On the other hand, the husbandman's comfort for the best performance is also a complex reaction to a number of environmental parameters, which, according to Emmanuel (2005), was clearly recognized as early as 1938. To man bioclimatic quantification is more complicated than indoor comfort due to various reasons. Psychological reasons have to do with human comfort 'expectations'; physiological differences – he said – arise from time spent indoors against outdoors (typically, long exposure in indoor situations as against short, quick exposure in the case of outdoors). Energetic differences arise from the variation between mean radiant temperature (MRT) and air temperature; he conclumded that, while it is safe to assume that these two are equal indoors, large differences exist between them in the outdoors (particularly in warm outdoors).

Emmanuel (2005) concluded that practical difficulties in measuring more than a few parameters kept initial attempts at quantifying bioclimate confined to only a few environmental variables. These included thermal comfort indices of temperature humidity index (THI) for both man and animal plus relative strain index (RSI) that takes care of the effect of clothing insulation and net radiation for man (Emmanuel, 2005; Marai *et al*. 2002; Nieuwolt, 1982). THI is calculated using air temperature and relative humidity. For man, it is given by Nieuwolt (1982) as:

$$THI = 0.8t + (RH\ t)\ /\ 500. \qquad (3)$$

For rabbits, Marai *et al*. (2002) arrived at the following equation:

$$THI = t - [(0.31 - 0.31(RH / 100))\ (t - 14.4)], \qquad (4)$$

where in both equations t is the air temperature (°C) and RH is relative humidity (%.).

The comfort limits for man were given thus for:

21≤THI≤24°C, 100% of the subjects felt comfortable;

24≤THI≤26°C, 50% of the subjects felt comfortable;

THI>26°C, 100% of the subjects felt uncomfortable.

The comfort limits for rabbit are defined as (Marai *et al*., 2002):

THI<27.8°C, absence of heat stress;

27.8 to 28.9°C, moderate heat stress;

28.9 to 30°C, severe heat stress;

THI>30°C, very severe heat stress.

However, according to both Marai *et al*. (2002) and Emmanuel (2005), the indicated ranges for man and rabbits were developed for the mid-latitude while it needed to be noted that in the tropical region both man and animals are likely to tolerate higher levels of THI due to acclimatization as well as variations in food habits, fur, clothing, and so on.

On the other hand, while the THI accounts for the thermal comfort effects of air temperature and relative humidity, the RSI allows for the effects of clothing insulation and net radiation (Emmanuel, 2005). For a standard man *ie* healthy 25 year old male, un-acclimatized to heat, in business clothing according to Emmanuel (2005) under specified conditions *ie* internal heat production = 100 $W\ m^{-2}$, wind speed = 1$m\ s^{-1}$ and no direct solar radiation RSI was given as:

$$RSI = (t - 21)\ /\ (58 - e), \qquad (5)$$

where: t is the air temperature (°C), and e is the vapour pressure (hPa). Emmanuel (2005) concluded that for comfort in a mid-latitude temperate region the following are the limits for man: when RSI is 0.1 (100% unstressed *ie* comfortable), 0.2 (75% unstressed), 0.3 (none of the occupants is stressed, this is the upper limit of comfort level), 0.4 (75% are stressed) and at 0.5 (all occupants are stressed). He mentioned that an RSI of 0.2 is the upper limit for elderly and those of ill health.

MATERIALS AND METHODS

An investigation was carried out using three different buildings at the Teaching and Research Farm (TRF) of the Obafemi Awolowo University, Ile-Ife, Nigeria (Latitude 07° 28'N and Longitude 04° 33'E), between the months of January and April, 2006. Two of the buildings were with two different inlet openings of 50 and 30% of the sides, while the outlet opening was 20% of the side. One of the buildings was oriented perpendicular (90°) and the other skewed at 45° to the direction of the north-east prevailing wind at the location. The third building is the production rabbitry building on the farm which has its major axis oriented in the east-west direction with both inlet and outlet openings equal *ie* 100% opening taking the full length and height of the sides.

Environmental parameters of temperature and relative humidity of both the inside and outside of the experimental buildings were monitored two times daily to obtain the direct effect of orientation, percent opening of inlets and outlets and their interaction on the thermal comfort levels of the building as evident in the rabbits' performance. The buildings internal environmental temperature ($T_{i,}$), relative humidity (RH) and external temperature (T_e) were measured using a Taylor 1442 Type Digital multimeter gauge. Also, for correlation purposes, a K-Type multimeter for temperature and a hygrometer for humidity were used; these allowed for more readings to be taken. The wind speed at the location was collected for the period considered from the TRF meteorological station which is proximate to the experimental station.

From the data collected throughout the period correlation analyses was done between the THI of the three different openings to determine the best opening for comfort of both animal and man as suggested by other researchers.

Data analysis

In order to better understand the effects of the different treatments and their interactions, data were subjected to statistical analyses using statistical analysis system procedure (SAS, 2000). Two-way analysis of variance (ANOVA) was performed to compare variations in performance characteristics of rabbits' production and physiological behaviours. Significance levels of 5 and 1% were used. Where significance was indicated, Duncan's multiple range test was used to separate the means.

RESULTS AND DISCUSSION

Figures 1 and 2 indicate the thermal comfort trend for both animal and man in the buildings, respectively, and Table 1 shows the values of THIs for both rabbit and man as well as the RSI for man, while Fig. 3 shows the RSI trends during the period. From Fig. 1 it was observed that the value of THI for rabbit varies with the changing periods of experiment in accordance to the variations in both temperature and relative humidity. The result of the analysis of variance (ANOVA) of the THI for rabbit with building orientation and ventilation opening level is presented in Table 2. From this Table it can seen that both building orientation and ventilation opening have a significant effect on the rabbit

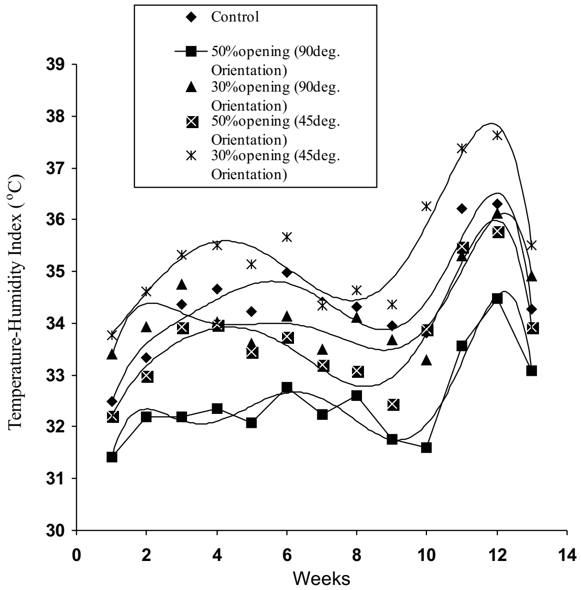

Fig. 1. Daily mean temperature humidity index THI (°C), trend for rabbits during the experiment period**.**

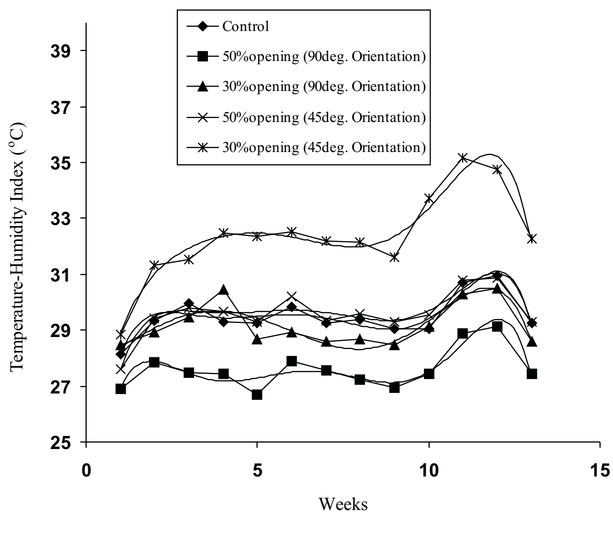

Fig. 2. Daily mean temperature humidity index (°C), trend for husbandmen during the experiment period.

T a b l e 1. Mean effect of treatments on building thermal comfort index (THI) for rabbit and man as well as relative strain index (RSI) for man

Orientation (°)	Opening (%)	THI_{rabbit}	THI_{man}	RSI_{man}
45	30	35.396	32.362	0.389
	50	33.823	29.759	0.287
90	30	34.213	29.168	0.250
	50	32.488	27.608	0.202
Control		34.333	29.497	0.271

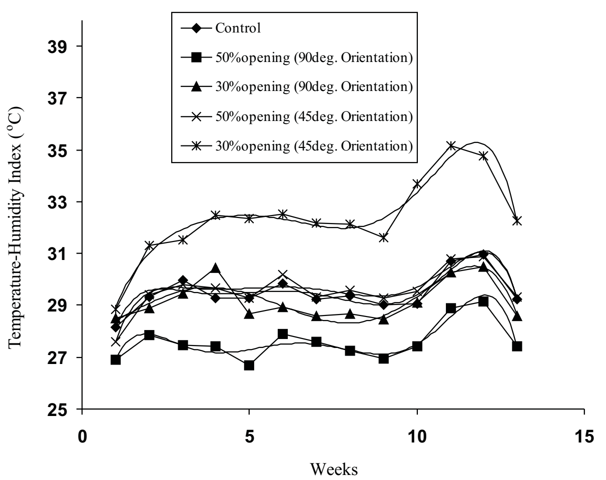

Fig. 3. Daily mean relative strain index trend for husbandmen during the experiment period.

pen THI at 1% level of significance. The Duncan multiple range tests presented in Table 3 show that the 50% ventila- tion openings with the highest height to length ratio of the inlet opening had a lower THI level of 32.488°C in 90° orientation building; this environment provides the most thermally comfortable condition for the rabbit in this study, since the lower the THI value the more comfortable is the microenvironment. The least thermally comfortable pens for the rabbits are seen in the 30% ventilation opening pens of the 45° orientation building that had the highest THI value of 35.396°C.

Considering the THI for man (Fig. 2, Table 1), and the result of ANOVA of THI with building orientation and ventilation opening presented in Table 4, it can be seen that both building orientation and ventilation opening have significant effect on the enclosure's THI for man at 1% level of significance. The Duncan multiple range tests presented in Table 3 show that the 50% ventilation openings of the 90° orientation building also had a lower THI level of 27.608°C and hence the most thermally comfortable environment for the workman. The least thermally comfortable environment for man is also seen in the 30% ventilation opening pens of the 45° orientation building that had the highest THI value of 32.362°C. While considering the relative strain index (RSI) for man (Fig. 3, Table 1), and the result of ANOVA for RSI

T a b l e 2. Analysis of variance (ANOVA) of temperature humidity index (THI) for rabbit with building orientation and ventilation opening level

Source of variation	Sum of squares	Degree of freedom	Mean square	F-ratio	Significance level
Model	110.099	17	6.476	33.04	<0.0001
Treatment	58.231	5	11.646	59.42	<0.0001
Replicates	49.503	12	4.125	21.05	<0.0001
Error	9.212	47	0.196		
Total	119.311	64			

Missing values have been excluded.

T a b l e 3. Multiple range analysis for temperature humidity index (THI) for rabbit (α = 0.05)*, number of treatments - 13

Duncan grouping	Mean	Treatment
A	35.396	45/30
A	34.333	Control
B	34.213	90/30
B	33.823	45/50
C	32.488	90/50

*Means with the same letter are not significantly different, control – East to West building orientation, 100% ventilation opening level:

building orientation (°)	ventilation opening level (%)
45/30- 45	30
45/50-45	50
90/30-90	30
90/50-90	50

From the results obtained in this study it can be seen that the 50% ventilation opening pens of the 90° orientation building provides the most favourable thermal comfort level for both animal and man, while the 30% ventilation opening pens of 45° orientation building gave the least thermally com- fortable environment. These results confirm the conclusions of various researchers on the fact that thermal comfort level in a production building is a function of amount of ventilation openings, the opening configuration, opening effectiveness and building orientation (Boutet, 1987; Lokhorst *et al.*, 1995; Grool Koerkamp, 1998; Ogunjimi *et al.*, 2007).

Although from the experiment the control building with both sides opened has the largest area that can admit more air into the building than the other openings, it was not able to provide the required low level comfort indicator (THI), this may be due to the equal amount of opening on both sides that enhances the entry of air from both sides with a possible eddy current (Boutet, 1987). Hot air that is expected to rise up to move out will continuously be mixing with the incoming ones but this current allows the mixing up of the incoming air with the already heat- and moisture-laden inside air. It is also noted that the control building is orientated in the East-West direction, which does not allow for the full incidence of the prevailing air flow. The 50% opening buildings produce the next higher amount of airflow rate and for both orientations the least in each case of THI and hence the higher comfort level. The 30% inlet opening type of building was seen not to be good enough for profitable production, for both animal and man, as less amount of air is allowed in.

For the tropical humid environment of the South-West of Nigeria type, a building having large openings on both sides (along the axis) with ridge vent as outlet will be an appropriate configuration. This type of building will, throughout the year, admit air from either side while the hot moist spent air will move out through the upper vent, cooling down the building, particularly at the animal and man occupation levels.

T a b l e 4. Analysis of variance (ANOVA) of temperature humidity index (THI) for man with building orientation and ventilation opening level

Source of variation	Sum of squares	Degree of freedom	Mean square	F-ratio	Significance level
Model	195.966	17	11.527	35.89	<0.0001
Treatment	153.412	5	30.682	95.54	<0.0001
Replicates	38.397	12	3.200	9.96	<0.0001
Error	15.094	47	0.321		
Total	211.060	64			

Missing values have been excluded.

T a b l e 5. Multiple range analysis for temperature humidity index (THI) for man (α = 0.05), number of treatments - 13

Duncan grouping	Mean	Treatment
A	32.362	45/30
B	29.759	45/50
B	29.497	Control
B	29.168	90/30
C	27.608	90/50

Explanations as in Table 3.

with building orientation and ventilation opening presented in Table 6 for man, it can equally be seen that both building orientation and ventilation opening have a significant effect on RSI of man at 1% level of significance. The Duncan multiple range tests presented in Table 7 show that the 50% ventilation openings of the 90° orientation building also had a lower RSI value of 0.202 and hence the least strain for the workman during work period; the highest RSI value of 0.389 can also be observed for the 30% ventilation opening pens of the 45% orientation building, hence providing the most strained environment for the workman.

T a b l e 6. Analysis of variance (ANOVA) of relative strain index (RSI) for man with building orientation and ventilation opening level

Source of variation	Sum of squares	Degree of freedom	Mean square	F-ratio	Significance level
Model	0.333	17	0.020	23.61	<0.0001
Treatment	0.246	5	0.049	59.17	<0.0001
Replicates	0.081	12	0.007	8.11	<0.0001
Error	0.039	47	0.001		
Total	0.372	64			

Missing values have been excluded.

T a b l e 7. Multiple range analysis for relative strain index (RSI) for man (α = 0.05) , number of treatments - 13

Duncan grouping	Mean	Treatment
A	0.389	45/30
B	0.287	45/50
B	0.271	Control
B	0.250	90/30
C	0.202	90/50

Explanations as in Table 3.

CONCLUSIONS

1. The results showed that both the amount of ventilating opening and building orientation have significant effects on the thermal comfort level of a building.

2. The larger the ventilating opening the more the comfort level as indicated by the THI value for both animal and man, so also is the level of RSI for man. In the same way, the closer the building orientation to putting the opening at a perpendicular situation to the incidence of the prevailing wind the more comfortable the environment becomes.

3. The lower the value of THI of an environment, the more is the comfort level for both animal and man; while the lower the RSI value the lesser is the strain on man. Although the THI (thermal comfort indicator) values are high and above the specified range of thermal comfort levels for both rabbits and man, they may have sustained the condition due to long time acclimatization in accordance to the observations of Marai *et al*. (2002) and Emmanuel (2005). This might have resulted in the relatively normal performance of both animals and man in these buildings particularly the 50% ventilation opening of the 90° orientation building pen.

4. However, for the tropical humid regions a building with adequate side opening having a ridge vent and at an orientation close to perpendicular to prevailing wind direction that will provide the fullness ventilation for an efficient rabbit production building is recommended.

REFERENCES

Barrington S.F., Zemanchik N., and Choiniere Y., 1994. Orientating livestock shelters to optimise natural summer ventilation. Transactions of the ASAE, 37(1), 251-256.

Bird R.B., Stewart W.E., and Lightfoot E.N., 1960. Transport Phenomena. J. Wiley and Sons, New York.

Bosco A.D., Castellini C., and Mugnai C., 2002. Rearing rabbits on a wire net floor or straw litter: behaviour, growth and meat qualitative traits. Livestock Prod. Sci., 75, 149-156.

Boutet T.S., 1987. Controlling Air Movement: A Manual for Architects and Builders. McGraw-Hill Book Comp., New York.

Diesch M.A. and Froehlich D.P., 1988. Production and environmental simulations in livestock housing. Transactions of the ASAE, 31(5), 1532-1539.

Duncan G.A., Loewer O.J. (Jr), and Colliver D.G., 1981. Simulation of energy flows in greenhouse: magnitudes and conservation potential. Transactions of the ASAE, 24(4), 1014-1021.

Egbunike G.N., 1979. The relative importance of dry- and wet-bulb temperatures in thermo-respiratory function in the chicken. J. Vet. Medicine, A, 26(7), 573-579.

Emmanuel R., 2005. Thermal comfort implications of urbanization in a warm – humid city: the Colombo Metropolitan Region (CMR), Sri Lanka. Building Environ., 40, 1591-1601.

Esmay M.L. and Dixon J.E., 1986. Environmental Control for Agricultural Buildings. AVI Publ. Comp., Inc. Westport, CO, USA.

Grool Koerkamp P.W.G., 1998. Review of emissions of ammonia from housing systems for laying hens in relation to sources, processes, building design and nature of handling. Reproduced in ammonia emission from aviary housing systems for laying hens inventory, characteristics and solution. J. Agric. Eng. Res., 59, 73-87.

Habeeb A.A., Marai I.F.M., and Kamal T.H., 1992. Heat stress. In: Farm Animals and the Environment (Eds C. Philips and D. Piggins). C.A.B. Int., Wallingford, U.K.

Lokhorst C., van Ouwerkerk E.N.J., and Voskamp J.P., 1995. Management support and climate control. In: Aviary Housing for Laying Hens (Eds H.J. Blokhusis and J.H.M. Metz). Agricultural Research Department, Institute for Animal Science and Health, ID-DLO, Lelystad; and Institute of Agricultural and Environ. Eng., IMAG-DLO Press, Wageningen, The Netherlands.

LPHSI, **1990.** Livestock and Poultry Heat Stress Indices, Agric. Eng. Guide. Clemson Univ. Press, Clemson Sci., 29634, USA.

Marai I.F.M., Habeed A.A.M., and Gad A.E., 2002. Rabbits' productive, reproductive and physiological performance traits as affected by heat stress: a review. Livestock Prod. Sci., 78, 71-90.

Markus T.A. and Morris E.N., 1980. Buildings, Climate and Energy. Pitman Publ. Comp., London.

Nääs I.A., Moura D.J., Buckin R.A., and Fialho F.B., 1998. An algorithm for determining opening effectiveness in natural ventilation by wind. Transactions of the ASAE, 41(3), 767-772.

Nieuwolt S., 1982. Tropical Climatology – An Introduction to the Climates of the Low Latitudes. J. Wiley and Sons, New York.

Ogunjimi L.A.O., Osunade J.A., and Alabi S.F., 2007. Effect of building orientation on environmental performance of farm building. Arid Zone J. Eng., 5 (in press).

SAS, **2000.** Statistical Analysis Software. Guide for Personal Computers. Release 8.1. SAS Institute Inc. Cary, NC, USA.