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Variation of Thermal Conditions and Heat-Moisture Balance in Caged-Poultry Houses with Different Roof Insulations

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Abstract: This research was carried out to investigate the impacts of different roof installations on heat-moisture balance and indoor thermal conditions of the poultry houses in cold seasons. Experiments were conducted in 3 different commercial type caged-poultry houses with the same capacity and characteristics but different roof insulations. Indoor and outdoor temperature and relative humidity values were measured for 5 months (October, November, December, January, February) to evaluate the effects of roof insulation on heat-moisture balances of the poultry houses. Results revealed the significance of insulation level of roof cover materials to keep the heat loss through structural elements at low levels. The heat loss from uninsulated roof (5.66 Wm^{-2} K) was almost 10 times higher than the heat loss from well-insulated roof (0.53 Wm^{-2} K).

Key words: Poultry house, environmental conditions, roof, insulation, heat-humidity balance, Turkey

INTRODUCTION

As it was in the other livestock production facilities, the basic objective in poultry facilities is to have the most economical and the highest yield in response to a certain investment and cost. These desired goals can only be achieved by using high yield animals and feeding them at sufficient levels in properly designed poultry houses with optimum environmental conditions.

Heat loss through structural elements via conduction, convection and radiation or heat gains should be kept at desired levels to provide optimum climatic environmental conditions in poultry houses. Proper insulation should be supplied over structural members by taking outdoor conditions into consideration to reach the desired indoor heat-moisture balance and to keep the environmental control levels at optimum.

In animal housing, the roof plays a primary role in the determination of the thermal exchanges of the animals (Liberati and Zappavigna, 2007, 2008; Turnpenny *et al*., 2000). Researches revealed significant insulation problems in animal housing especially over roofs and indicated 65% of insulation problems in animal housing were observed over roofs (Patterson and Mehta, 2001). Roofs prevent structures from the impacts of wind, rainfall and snow etc., like outer factors and function as the most significant structural member in environmental control. They have the highest construction, repair and maintenance costs. Since, roof materials are directly effective on air volume needed by animals to provide indoor heat balance and resists the outer loads (snow and wind), proper calculations should be performed for roof members during the design phase of buildings.

Selection of roof cover material affects the indoor environmental conditions of poultry houses. Since, the roofs have higher surface areas and able to be constructed with more diverse materials than the walls, heat flow through roofs is more than the walls. Heat loss is obvious through roofs in Winters and heat gain in Summers. Proper insulation should be provided to diminish this bilateral heat movement.

This research was carried out to investigate the impacts of different roof insulations on heat loss through structural members, heat-moisture balance and indoor thermal conditions of the poultry houses in cold seasons.

MATERIALS AND METHODS

Three commercial-type laying hen poultry houses, selected as the material of this study are located in Tokat province (39°51'N and 40°55'E) in Central Black Sea region of Turkey. Long term annual average lowest temperature of the region is 8.1°C and the highest is 14.2°C. Average relative humidity varies between 56-73%. Long-term average precipitation is between 381.8-586.2 mm and precipitation varies with months (Anonymous, 2010).

Poultry houses are oriented along North-South direction and they have a width of 12 m, length of 40 m and height of 2.80 m. Poultry houses use natural ventilation systems and each one has 11 air outlets with a size 0.75 m^2 over the ridge of the roof and 22 windows along the longer side walls of the house. Total window space corresponds to 3.8% of total floor space. Ventilation practices were tried to be kept at same levels in poultry houses during the research period. For wall construction, 19×19×13.5 cm hallow bricks, 2 cm inner and 3 cm outer lime-cement grout plaster were used. The poultry houses has 10,000 White Isa Brown race laying hens, placed into 5 hens $cage^{-1}$ with automatic feeder and waterer. Cages cover 426 cm^2 of floor space and house volume per hen is 0.21 m^3.

Insulation material configurations for poultry houses were as follows: For the first house (P1), 5 cm glass wool over wood siding + bitumen felt + French tile; for the second house (P2), 3 cm polystyrene over wood siding + corrugated asbestos cement roofing; for the third house (P3), only corrugated asbestos cement roofing without insulation materials. Heat transfer coefficients and surface areas of structural members for each poultry house were shown in Table 1.

To perform heat-moisture balance analysis and to monitor temperature-relative humidity variations, hourly indoor and outdoor temperature and relative humidity measurements were taken from three different locations of the houses by electronic measurement and data logging device (HOBO RH/Temp, Type: HO8-003-02, USA) during the months of October, November, December, January and February.

Methods and equations provided by Esmay (1974), MWPS (1983), Maton *et al.* (1985), TS 5016 (1987), TS 5087 (1978), Albright (1990), ASAE (1996), Lindley and Whitaker (1996) and CIGR (1999) were used in calculations for heat transfer coefficients, heat-moisture balance and ventilation. Heat transfer coefficients of structural members were taken from Owen (1994). Heat and moisture released by animals were calculated by using the equations specified by CIGR (1984, 1999). Indoor design temperature was taken as 18°C and relative humidity was taken as 70% (CIGR, 1984; Clark and McArthur, 1994; Ekmekyapar, 1993).

Univariate variance analysis was used to compare the poultry houses statistically and Tamhane's post-hoc test was used bilaterally when the differences among groups were found to be significant. Simple correlation analysis (Pearson correlation coefficient) was used to investigate the relationships among variables.

Table 1:Heat transfer coefficients and surface areas of structural members

Poultry house	Area and coefficient	Structural materials: Roof	Wall	Windows	Door
	Area (m^2)	515	290	18.5	4.40
P1	Coefficient (Wm^{-2} K)	0.53	1.69	5.88	6.04
P2	Coefficient (Wm^{-2} K)	0.99	-	-	-
P3	Coefficient (Wm^{-2} K)	5.66	-	-	-

Stepwise regression analysis was used create a model with variables. Significance level was taken as p = 0.01 and lower values were accepted as significant.

RESULTS AND DISCUSSION

Minimum, maximum and mean indoor and outdoor temperature and relative humidity values were shown in Table 2, variation in indoor and outdoor measurements were shown in Fig. 1 and variations in a single day were shown in Fig. 2.

Distribution of indoor and outdoor temperatures of the houses in a day and differences among them varied with regard to insulation levels over the structural members. Indoor temperatures had parallel trend with outdoor temperatures. Mean temperatures observed in P1-P3 were 18.9, 17.0 and 11.8°C, respectively. Temperatures were below the optimum levels at 46% of the time in P1 at 65% of the time in P2 and 87% in P3. Mean indoor relative humidity values were measured as 59.9% in P1, 63.7% in P2 and 69.6% in P3. Although, there were not sudden changes in outdoor temperatures, faster changes were observed in indoor temperatures of P3 in a short time (1-2 h).

Indoor and outdoor temperature difference in poultry house without insulation was lower than the others and generally closer maximum temperatures were observed. Increased minimum and mean temperatures were shown with increasing level of insulation. Mean and maximum indoor relative humidity increased with decreasing insulation levels.

Differences in temperature and relative humidity values of poultry houses were found to be significant ($p<0.0001$). The highest relationship between outdoor and indoor temperature was observed in P3 and it was followed by P2 and P1. Level of relationship between outdoor and indoor relative humidity was found to be significant, respectively in P1-P3 ($p<0.0001$). Weak

Table 2: Minimum, maximum and mean indoor and outdoor temperature and relative humidity values for poultry houses

Values	Poultry house	T_{out} (°C)	T_{in} (°C)	Rh_{out} (%)	Rh_{in} (%)
Minimum	P1		9.8		33.7
	P2	-17.2	6.2	42.8	31.7
	P3		0.5		30.7
Maximum	P1		33.2		72.7
	P2	33.0	33.8	95.5	85.0
	P3		32.3		100.0
Mean	P1		18.9		59.9
	P2	6.9	17.0	69.1	63.7
	P3		11.9		69.6

T_{out} = The outdoor temperature; T_{in} = Indoor temperature; RH_{out} = The outdoor relative humidity; RH_{in} = The indoor relative humidity

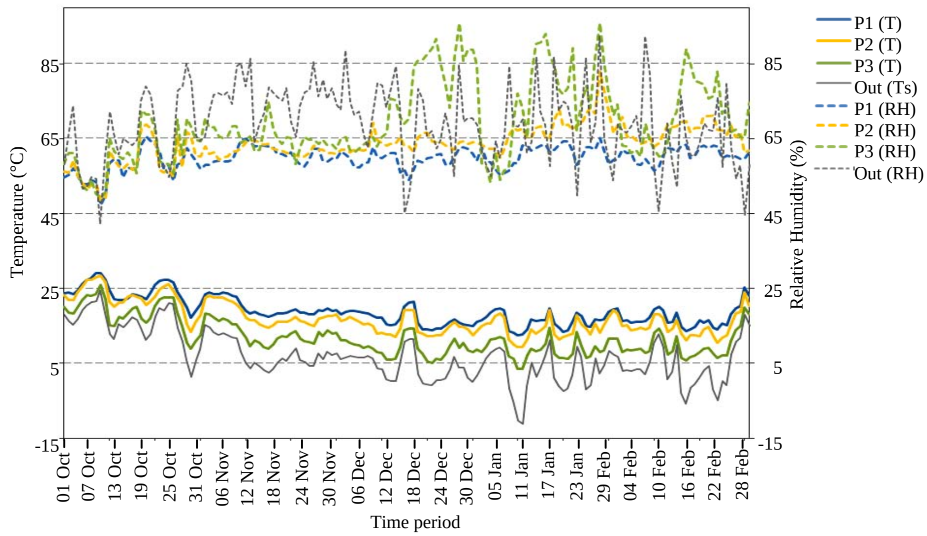

Fig. 1: Variations of indoor-outdoor temperature and relative humidity

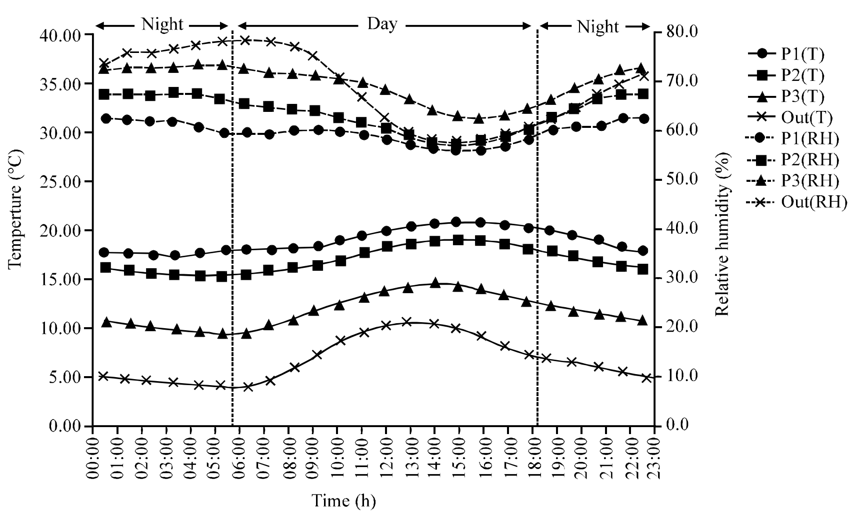

Fig. 2: Variations of indoor-outdoor temperature and relative humidity in a single day

but significant relationships were observed between temperature and relative humidity values as of r = -0.418 in P1, r = -0.606 in P2 and r = -0.547 in P3 ($p<0.0001$). Results revealed that indoor temperatures were significantly affected by outdoor temperatures, outdoor and indoor relative humidity and the greatest effect was observed by outdoor temperature. Regression analysis revealed positive relationships between indoor temperature and outdoor temperature-relative humidity and negative relationships between indoor temperature and indoor relative humidity. Also, combined effects of indoor-outdoor temperature and outdoor relative humidity on indoor relative humidity were found to be significant (Fig. 3).

Yield performances of hens in caged poultry houses are significantly affected by structural and climatic environmental conditions. Environmental health is among the most significant climatic environmental factor effecting especially the physiological activities, health and yield of hens and also the health of poultry workers. Radiation from the building shell may affect interior dry-bulb temperature, cooling and heating costs and environmental comfort if exposed directly to the building interior surface (Allen *et al*., 1993). The temperature range where the sensible heat loss of the animal remains fairly constant is the thermal zone where the most efficient feed conversion will occur. Below this temperature, lower critical temperature, the animal will use feed energy especially to maintain body temperature. The critical temperature is the point where metabolic heat production increases to maintain a constant body temperature and therefore, environmental temperature should not be

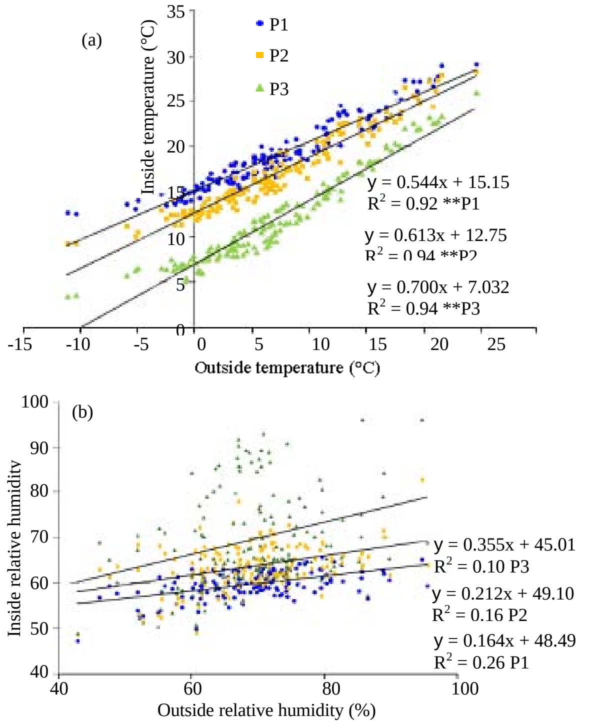

Fig. 3: Relationship between indoor and outdoor; a) Temperature and b) Relative humidity

allowed to go below the critical temperature to maintain efficient growth (Scott *et al*., 1983). Clark and McArthur (1994) and CIGR (1984) recommended the optimum temperature for hens as 18°C. Charles (1994) and MWPS (1983) reports proper temperature range for hens as 10-20°C. McArdle (1972) indicated that temperature in story-type caged houses should be between 12.8-26.7°C. Sainsbury (1981) reported the optimum temperature range as 15-21°C. Optimum relative humidity ranges were specified as 50-75% by Ensminger (1971) and as 50-80% by MWPS (1983).

Total heat, sensible heat and water vapor production of the hens during the research period were shown in Table 3. Sensible heat production values per hen for P1, P2 and P3 poultry houses were respectively 5.36, 5.63 and 6.34 W; latent heat production values were respectively 2.82, 2.60 and 2.20 W; water vapor production values were 4.13, 3.80, 3.22 g h^{-1}.

In a well-designed poultry house, average sensible heat production per hen should be 5.60 W, latent heat production should be 2.57 W and water vapor production should be 4.36 g h^{-1}.

Heat losses through structural members of the poultry houses were shown in Table 4 and heat-moisture balance analysis were shown in Table 5.

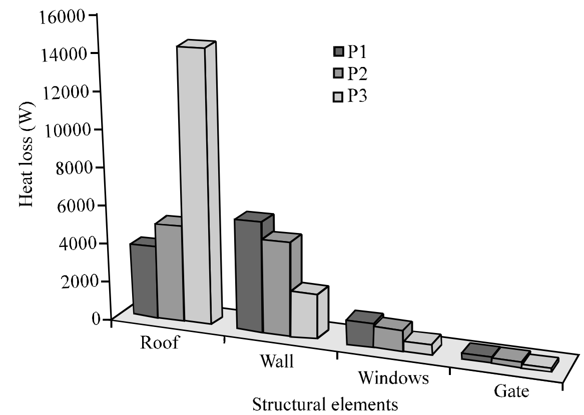

Fig. 4: Means of heat loss

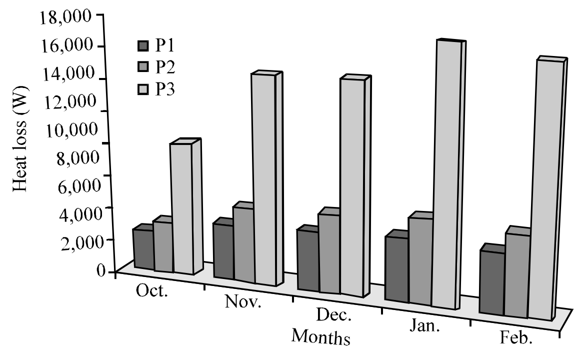

Fig. 5: Monthly heat losses

Table 3:Average heat and water vapor production per hen during research

Poultry house	Months	Total heat (W)	Sensible heat (W)	Total moisture (g h^{-1})
P1	10	8.11	4.34	6.40
	11	8.18	5.26	4.96
	12	8.21	5.74	4.19
	1	8.22	5.78	4.14
	2	8.20	5.68	4.28
P2	10	8.13	4.62	5.96
	11	8.20	5.55	4.50
	12	8.26	6.01	3.82
	1	8.30	6.04	3.84
	2	8.27	5.96	3.92
P3	10	8.21	5.37	4.82
	11	8.37	6.20	3.68
	12	8.71	6.73	3.36
	1	8.76	6.77	3.36
	2	8.68	6.63	3.48

Heat losses through structural members were shown in Fig. 4, monthly heat losses through roof members were shown in Fig. 5 and hourly heat loss through roof in a single day was shown in Fig. 6.

Average heat loss through structural members in P1 was 3890 W through roof, 5882 W through walls, 1309 W through windows and 319 W through doors; heat loss in P2 was 5139 W through roof, 4937 W through walls, 1099 W through windows and 268 W through doors in P3

Table 4: Heat losses in poultry houses (W)

Poultry house	Months	At current conditions						At optimum conditions (18°C and 75% RH)					
		q_r	q_w	q_{win}	q_d	q_{tot}	Q_v	q_r	q_w	q_{win}	q_d	q_{tot}	Q_v
P1	10	2818	4261	949	231	8260	34164	1949	2947	656	160	5713	19238
	11	3966	5996	1335	326	11623	33660	3465	5239	1166	285	10184	20571
	12	4137	6255	1392	340	12123	32033	4529	6848	1525	372	13273	20623
	1	4382	6626	1475	359	12842	31700	4879	7377	1642	400	14298	20940
	2	4166	6300	1403	342	12210	30673	4459	6902	1536	374	13272	19559
P2	10	3584	3731	798	194	8308	35604	3068	2947	656	160	6831	19238
	11	5245	5038	1121	273	11678	33789	5454	5239	1166	285	12145	20571
	12	5439	5225	1163	284	12111	32095	7128	6848	1525	372	15873	20623
	1	5853	5622	1251	305	13031	27057	7679	7377	1642	400	17098	20940
	2	5450	5235	1165	284	12134	25556	7186	6902	1536	374	15999	19559
P3	10	9304	1560	348	85	11296	36572	17578	2947	656	160	21341	19238
	11	14481	2421	533	128	17562	45256	31249	5239	1166	285	37939	20571
	12	14604	2448	545	133	17730	32120	40840	6848	1525	372	49585	20623
	1	17346	2909	648	158	21061	30090	43997	7377	1642	400	53417	20940
	2	16481	2763	615	150	20009	29441	41173	6902	1536	374	49986	19559

q_r is the heat loss through roof; q_w is the heat loss through wall; q_{win} is the heat loss through windows; q_d is the heat loss through doors; q_{tot} is the net heat output through the structural elements; Q_v is the heat loss removed by ventilation

Table 5: Heat requirements at various temperatures (W)

Poultry house	Months	Temperature (°C)			
		13	15	18	20
P1	10	63175	50492	28079	9580
	11	48310	38821	22188	8370
	12	41211	33123	18910	7341
	1	39618	31603	17515	6050
	2	42040	34050	20040	8139
P2	10	62880	49825	26983	9466
	11	47509	58972	20051	4869
	12	39540	31080	20261	3757
	1	37745	29360	18781	2475
	2	40310	31986	21142	4865
P3	10	52466	35915	47809	-7450
	11	33500	18822	-3151	-24600
	12	17866	4591	-17402	-34158
	1	13465	322	-21604	-38256
	2	18401	5223	-16568	-33144

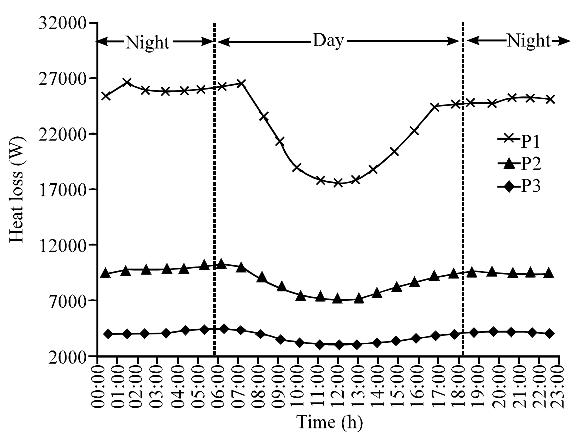

Fig. 6: Hourly heat loss through roof in a single day

the value was 14462 W through roof, 2423 W through walls, 547 W through windows and 131 W through doors. Average total heat loss through structural members for P1-P3 poultry houses were respectively 11400, 11443 and 17563 W. Percentages of total heat loss through roof, wall, window and door were determined as respectively 35, 51, 11, 3% in P1; 45, 43, 10, 2% in P2; 82, 14, 3, 1% in P3. Ratio of heat loss through structural members to total heat loss for P1-P3 was realized as 24, 26 and 42%, respectively. The largest heat loss through structural members was observed during the coldest month of January between the hours 04:00-06:00. Results revealed increasing heat losses with decreasing insulation levels.

Differences in heat losses through roofs of poultry houses were found to be significant ($p<0.0001$). While the difference between P1 and P2 was not found to be significant ($p = 0.997$), the differences in other comparisons were found to be significant ($p<0.0001$). Also the relationship between outdoor temperature and heat loss through roof was found to be significant ($p<0.0001$). During the design phase, total heat losses were calculated as 11742, 14037 and 43852 W for P1-P3, respectively and heat loss through roof was calculated as 4007 W for P1, 6306 W for P2 and 36119 W for P3. Under optimum temperatures, percentage of heat losses through structural members of P1-P3 were determined, respectively as 34, 45 and 82% through roofs as 52, 43, 14% through walls as 1, 10, 3% through windows as 3, 2, 1% through doors. Ratio of heat loss through structural members to total heat loss was calculated as 33% for P1, 34% for P2 and 63% for P3. Actual hourly measurements revealed that heat balance was not able to be supplied at 2.44% of the time in P1, 2.46% in P2 and 60.91% in P3. For poultry house without roof insulation, heat balance was not able to be provided at 16.8% of the time in October, 59.14% in November, 82.93% in December, 74.73% in January and 65.04% in February.

Under design conditions, average heat loss through ventilation was calculated as 23533, 23574 and 43768 W, respectively for P1-P3. Heat loss through structural members of P1 and P2 is obviously lower than the heat loss through ventilation. The highest heat loss was determined for the poultry house without roof insulation (P3) and it was followed by P2 and P1. Heat loss through structural members of P3 was almost 1.5 times of the heat loss through ventilation.

Heat loss factor indicating the heat loss through structural members per hen provides an idea about whether or not a heat balance can be established in a poultry house. Heat loss factor was determined as 0.095 W/°C for P1, 0.114 W/°C for P2 and 0.349 W/°C for P3. Results revealed that both average heat transfer and heat loss factor are effective on heat balance of poultry houses and consequently the availability of the house for production.

Heat balance calculations revealed increasing heat deficit and extra heat source with decreasing insulation over the roof. Heat loss through structural members reaches to the highest level with decreasing roof insulation during the coldest hours of a day and less heat loss is observed with insulated roofs. Heat requirement increases during the night hours.

In poultry house without insulation (P3), heat transfer coefficients were higher than the recommended values providing the minimum heat loss through structural members and the house has also high heat loss factor. Therefore, it seems impossible to provide a heat balance in most of the time during the Winter months. An increasing extra heat source is needed in this poultry house from November to Spring to keep the indoor temperature at optimum levels. The heat released by hens was not able to compensate the heat loss through structural members and ventilation during especially cold days. Lack of roof insulation caused to have higher loss of sensible heat released by hens than the other houses. In this case, indoor temperature will decrease below the design temperature of 18°C even with minimum ventilation in Winter months. Decrease in indoor temperature will increase with increasing heat deficit of the structure.

Sometimes minimum ventilation rates are reduced even more to preserve indoor heat balance of the poultry houses with negative heat balance. Ventilation rates are significantly reduced or even stopped in some facilities during the cold Winter days. However, reduction in minimum ventilation rates may create excessive moisture accumulation in the house and may change the gas concentration of the house.

Heat loss through structural members plays a critical role for indoor heat balance of poultry house. Heat loss through ventilation is inevitable for every house but heat loss through structural members can be kept under control. If the heat loss through structural members can be kept at desired levels by a proper insulation, indoor climatic conditions can be kept at desired levels even with sufficient ventilation at severe outdoor conditions. Previous studies over the poultry houses of the region revealed that insulation materials generally were not used in structural members and insulation was used only for roof members (Karaman *et al*., 2005).

Physical characteristics of roof material and insulation level play a critical role in keeping climatic environmental conditions of poultry houses at optimum levels since roof surface constitutes large part of entire structure and in direct contact with solar radiation and irradiation and more effective than the other structural members in keeping bioclimatic conditions at optimum levels. That assigns a great role to roof insulation for heat balance of poultry houses. In current study, almost 80% of heat loss in uninsulated poultry house was observed through the roof. Such a high rate of heat loss through roof indicates the significance of roof insulation levels and inside temperatures of roof surfaces in bioclimatic performance of poultry houses. Rising heated indoor air is also in direct contact with interior roof surface. Therefore better insulation should be provided for roofs than the other structural members. Several other researchers also indicated the significance of roof insulations for poultry houses (Amendola *et al*., 2001; Liberati and Zappavigna, 2007, 2008).

Moisture balance calculations revealed the ventilation rates/hen as 1.09, 1.18 and 2.77 m^3 h^{-1}, respectively for P1-P3 and minimum ventilation rate for proper ventilation during winter months was calculated as 0.76 m^3 h^{-1}. Since indoor-outdoor temperature difference is higher in insulated houses, ventilation capacity was found to be lower in well-insulated poultry houses than the one without insulation.

Dew point temperatures increased with increasing roof insulation levels (Fig. 7). The lowest dew point temperature was observed in uninsulated poultry house. Average roof internal surface temperatures were realized as 17.98, 15.75 and 8.39°C and dew point temperatures were determined as 10.95, 9.99 and 6.24°C, respectively for P1-P3 (Table 6).

Differences between dew point and roof internal surface temperatures were found to be significant ($p<0.0001$). Positive significant relationships were also observed between roof internal surface temperatures and dew point temperatures ($r = 0.936$ for P1; $r = 0.910$ for P2; $r = 0.830$ for P3, $p<0.0001$).

Dew occurs over the surfaces of structural members when the internal surface temperatures of structural members are below the dew point temperature of indoor

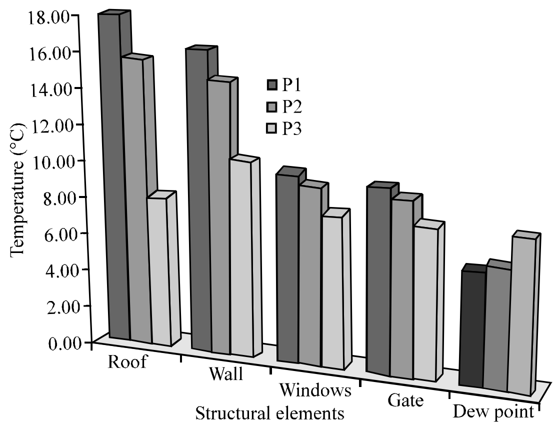

Fig. 7: Average internal surface and dewpoint temperatures of structural members

Table 6: Average dewpoint and roof internal surface temperatures in poultry houses

Poultry house	Months	Dew point (°C)	Roof internal surface temperature (°C)
P1	10	15.17	23.46
	11	12.19	19.01
	12	8.92	15.80
	1	8.91	15.42
	2	9.51	16.10
P2	10	14.02	21.86
	11	10.61	16.74
	12	7.89	13.39
	1	8.58	13.02
	2	8.82	13.62
P3	10	10.65	16.37
	11	6.64	9.31
	12	4.85	5.52
	1	4.36	4.71
	2	4.61	5.91

air. While there were not any dews over the internal surfaces of structural members in P1 and P2, dew was observed in 29% of the time in an hourly measurement over the internal surfaces of roof members in P3. During the measurement period, dew was visible over the internal roof surfaces in 1% of the time in October, 2% in November, 9% in December, 11% in January and 7% in February.

Under design conditions, temperatures of roof internal surfaces were determined as 17.14, 16.65 and 10.26°C, respectively for P1-P3 and dew point temperature was calculated as 12.53°C. Calculations revealed that there supposed to be no dew over internal roof surfaces in P1 and P2 and dew on 70% of the time in P3.

Simple heat transfer calculations demonstrate that variations of interior surface temperatures increase with decreasing insulation. Stefan-Boltzman's equation indicates heat emitted from a surface increases with the fourth power of surface absolute temperature. Therefore, enhanced environmental comfort and reduced heating and cooling costs are obtained by reducing differences between surface temperature and dry-bulb temperature of the enclosed air space (Allen *et al.*, 1993).

Average heat transport coefficients of poultry houses were found to be 1.15 Wm^{-2} K for P1, 1.37 Wm^{-2} K for P2 and 4.22 Wm^{-2} K for P3. Proper heat balance should so be provided in poultry houses that both heat loss should be reduced and dew should be prevented. Therefore, roofs of poultry houses should have a heat transfer coefficient of 0.91 Wm^{-2} K recommended by ASAE (1993, 1995) for climate zones similar to research site.

CONCLUSION

In this study, effects of different construction and insulation materials on heat transfer through structural members were investigated and indoor temperature and relative humidity of the poultry houses evaluated with regard to optimum values to be provided. An extra heat source is needed when the indoor temperature gets below the optimum level and temperature should be decreased when the value is above the optimum levels. Proper selection of roof insulation materials will probably eliminate the need for an extra heat source and the heat released by hens will be sufficient. Results revealed significance of roof insulation in keeping heat loss from structural members at low levels during especially Winter months and in providing optimum environmental conditions in poultry houses.

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