Article

Analysis of hygrothermal conditions for laying hens in the state of Oaxaca

Ángel Rosario Diaz[1§]
Rafael Alavez Ramirez[1]
Magdaleno Caballero Caballero[1]
Fernando Chiñas Castillo[2]
José Luis Montes Bernabé[1]
María Eugenia Silva Rivera[1]

[1]Instituto Politécnico Nacional- CIIDIR Unidad Oaxaca, Hornos No. 1003, Col. Noche Buena, Municipio de Santa Cruz Xoxocotlán CP. 71230, Oaxaca. Tel: (951) 517 0610 Ext. 82700. (arrafael@yahoo.com.mx; mcaballeroca@gmail.com; mbernabejoseluis@yahoo.com.mx, marusr@yahoo.com). [2]Tecnológico Nacional de México/ Instituto Tecnológico de Oaxaca, Departamento de Ingeniería Mecánica, Calz. Tecnológico No. 125, CP. 68030, Oaxaca, Oaxaca. Tel. (951) 50 15016. (fernandochinas@gmail.com).

[§]Autor para correspondencia: ing.luisangelrosariodiaz@gmail.com.

Abstract

For the passive design and location of a poultry farm it is necessary to know the thermal regime of the environment and that of the laying hens. The extreme conditions can cause death due to heat stress to the birds as well as a significant drop in production. The objective of this work was to elaborate the statistical analysis of the polygon of hour comfort of laying hens based on the temperature and humidity index (ITH), for the 9 bioclimates in the state of Oaxaca. Initially, bibliographic data were collected to determine the thermal comfort zone and the optimal ITH. Subsequently, it was determined that the ranges proposed by all the authors are met for a better production with the comfort temperature values for the hens, in the range between 18 °C -22 °C and relative humidity between 60% - 70%. Then, an hourly analysis of the hygrothermal conditions in which the bird is found was carried out by calculating the hourly ITH. The results show that laying hens have an emergency hygrothermal condition and danger during the year in the following proportion: warm bioclimate 20.14% in emergency condition and 32.99% in dangerous condition; humid warm bioclimate 4.86% in emergency condition and 38.54% in dangerous condition; warm dry bioclimate in 1.74% in emergency condition and 18.75% in dangerous condition.

Keywords: comfort hygrothermal conditions of laying hens, heat stress, temperature and humidity index (ITH) of laying hens.

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Introduction

In any type of poultry operation, whether of broiler chickens, commercial egg layers, breeders, or anywhere working with live birds, the environmental factors that have a determining influence are temperature, relative humidity, ventilation and lighting (Vaca, 2003). Temperature and humidity are the most influential factors (Sedat *et al*., 2007; Ajakaiye *et al*., 2011; Guevara *et al*., 2013). Having adequate environmental requirements will allow bird growth, stress reduction, egg production, improved fertility and efficient food processing (Weaver, 2002b). Posture hens do not adapt well to extreme temperatures and it is very important that they stay within their thermo-neutral zone of comfort (Weaver, 2002a) since, in cold climates, the bird will require more energy than when the weather is hot; the consumption of food will be reduced by a smaller percentage, for each degree Celsius of increase in temperature Craig (2002).

The ITH is one of the most widespread indicators to know the thermal regime that an environment presents. The knowledge of the thermal regime of the environment, together with the thermal requirement of laying hens, is a useful tool for making decisions regarding the design of the infrastructure. Therefore, the objective of this work was to develop an analysis of the hour comfort polygon of laying hens based on the ITH for the 9 bioclimates present in the state of Oaxaca.

Materials and methods

To determine the thermal comfort zone of the laying hens, bibliographic data of the best egg production under hygrothermal conditions were collected (Table 2), as well as references of the ITH where the best egg production was also obtained (Table 3). Once these two parameters were obtained, a table of ITH values was made to limit the comfort zone of the bird and carry out the climatic and parametric analysis of the site (Figure 1).

	59%	60%	61%	62%	63%	64%	65%	66%	67%	68%	69%	70%	71%	72%
14 °C	57.5608	57.552	57.5432	57.5344	57.5256	57.5168	57.508	57.4992	57.4904	57.4816	57.4728	57.464	57.4552	57.4464
15 °C	58.9549	58.956	58.9571	58.9582	58.9593	58.9604	58.9615	58.9626	58.9637	58.9648	58.9659	58.967	58.9681	58.9692
16 °C	60.349	60.36	60.371	60.382	60.393	60.404	60.415	60.426	60.437	60.448	60.459	60.47	60.481	60.492
17 °C	61.7431	61.764	61.7849	61.8058	61.8267	61.8476	61.8685	61.8894	61.9103	61.9312	61.9521	61.973	61.9939	62.0148
18 °C	63.1372	63.168	63.1988	63.2296	63.2604	63.2912	63.322	63.3528	63.3836	63.4144	63.4452	63.476	63.5068	63.5376
19 °C	64.5313	64.572	64.6127	64.6534	64.6941	64.7348	64.7755	64.8162	64.8569	64.8976	64.9383	64.979	65.0197	65.0604
20 °C	65.9254	65.976	66.0266	66.0772	66.1278	66.1784	66.229	66.2796	66.3302	66.3808	66.4314	66.482	66.5326	66.5832
21 °C	67.3195	67.38	67.4405	67.501	67.5615	67.622	67.6825	67.743	67.8035	67.864	67.9245	67.985	68.0455	68.106
22 °C	68.7136	68.784	68.8544	68.9248	68.9952	69.0656	69.136	69.2064	69.2768	69.3472	69.4176	69.488	69.5584	69.6288
23 °C	70.1077	70.188	70.2683	70.3486	70.4289	70.5092	70.5895	70.6698	70.7501	70.8304	70.9107	70.991	71.0713	71.1516
24 °C	71.5018	71.592	71.6822	71.7724	71.8626	71.9528	72.043	72.1332	72.2234	72.3136	72.4038	72.494	72.5842	72.6744
25 °C	72.8959	72.996	73.0961	73.1962	73.2963	73.3964	73.4965	73.5966	73.6967	73.7968	73.8969	73.997	74.0971	74.1972
26 °C	74.29	74.4	74.51	74.62	74.73	74.84	74.95	75.06	75.17	75.28	75.39	75.5	75.61	75.72
27 °C	75.6841	75.804	75.9239	76.0438	76.1637	76.2836	76.4035	76.5234	76.6433	76.7632	76.8831	77.003	77.1229	77.2428
28 °C	77.0782	77.208	77.3378	77.4676	77.5974	77.7272	77.857	77.9868	78.1166	78.2464	78.3762	78.506	78.6358	78.7656

Figure 1. ITH values obtained from equation 1.

Obtaining optimal hygrothermal conditions for the production of laying hens

According to the World Meteorological Organization (1989) (Table 1) 4 different ITH values are shown for animals in production that define their hygrothermal condition, which are: normal, alert, danger and emergency.

Table 1. Referential ITH values for animals in production.

ITH	Condition
< 70	Normal
71 – 79	Alert
80 – 83	Danger
> 84	Emergency

In the Table 2 shows the range of values of relative humidity and temperature for which the best results in egg production were obtained. Talukder *et al*. (2010) evaluated the effect of different environmental conditions on the performance of laying hens, gathering data on temperature, relative humidity, ammonia concentrations and carbon dioxide. The parameters evaluated were: egg production, food consumption, weight and egg shape, showing that the tolerable temperature of the hens ranges from 15 °C -27 °C. At temperatures above 27 °C, food consumption, weight and egg shape begin to be affected. Relative humidity has a lower impact on the production, weight and shape of the egg.

Table 2. Temperature (T) and relative humidity (RH) obtained for a good production of laying hens.

T. Minimum	T. Maximum	HR. Minimum	HR. Maximum	Reference
15 °C	27 °C	54%	70%	Talukder *et al*. (2010)
16 °C	25 °C			Cavalchini *et al*. (1990)
13 °C	24 °C	40%	80%	FAO (2011)
18 °C	24 °C			Bonilla and Díaz (2003)
18 °C	24 °C			Bell and Weaver, Jr. (2002)
16 °C		60%	75%	Echevarría and Miazzo (2002)
18 °C	30 °C	60%	70%	Vaca (2003)

Obtained the optimum temperature and humidity ranges, proposed by the different authors, the ITH was used to limit these comfort values. Table 3 shows that in some investigations (Lacetera, 2003; Guevara *et al*., 2013), there are 4 different values for the ITH that are: normal, alert, danger, emergency. St-Pierre *et al*. (2003) carried out an analysis using an ITH< 70 for laying hens with the purpose of demonstrating that the economic losses in the poultry industry of the United States of America were due to the fact that the animals were reared in zones and seasons where the temperature leaves the comfort zone of the animal.

Table 3. References of ITH values with good egg production.

ITH Normal	ITH Alert	ITH Danger	ITH Emergency	Reference
< 70	71-79	80-83	> 84	Guevara *et al.* (2013)
< 70				Ajakaiye and Pérez (2011)
< 70				St-Pierre *et al.* (2003)
< 70				Karaman *et al.* (2007)
< 74	75-78	79-83	> 84	Lacetera (2003)

Climate and parametric analysis of the site

The classification of the bioclimates was made using the climatic classification proposed by García, which is an adaptation of the Köppen climate classification system (2004), for existing bioclimates in Mexico. The representative meteorological station was randomly selected from a set of meteorological stations that belong to the same bioclimate because they are within the same range of temperature and annual rainfall.

Results and discussion

Determination of the thermal comfort zone for laying hens

A table was elaborated (Figure 1) with the determination of ITH values, using the equation (Dikmen and Hansen, 2009):

$$ITH = (1.8 \times Tdb + 32) - [(0.55 - 0.0055 \times RH) \times (1.8 \times Tdb - 26.8)] \quad \text{Equation 1}$$

Where: Tdb= represents the dry bulb temperature in °C; and RH= the relative humidity in (%).

It was determined that for the values: comfort temperature for hens in the range between 18 °C-22 °C and relative humidity between 60%-70%, the ranges proposed by all authors for a better production of the Table are met 2 and do not exceed values greater than 70 of ITH proposed by the authors of Table 3.

The green color shows the ITH values in the range of temperatures and relative humidities proposed as comfort parameters found in this research work.

Analysis by bioclimate

Using the equation of Dikmen and Hansen (2009) and the hourly temperature and humidity analysis proposed by Olygey (2014), the schedule conditions are shown for each of the existing bioclimates in the state of Oaxaca.

For the analysis of this semi-cold bioclimate, the standardized annual data of meteorological station number 20400 located in the municipality of San Pedro Quiatoni, Oaxaca, were acquired. These data show us that the chicken will only be in the hygrothermal state of alert 7.64% of the year as shown in Figure 2.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	56.46	54.89	53.54	52.5	51.85	51.63	52.24	53.96	56.46	59.31	62.09	64.45	66.2	67.26	67.62	67.49	67.11	66.47	65.59	64.45	63.1	61.56	59.89	58.16	60
Febrero	56.41	54.86	53.52	52.49	51.84	51.62	52.23	53.93	56.41	59.22	62.16	64.82	66.79	67.97	68.36	68.22	67.8	67.09	66.1	64.83	63.3	61.56	59.8	58.09	60
Marzo	58.97	57.31	55.87	54.76	54.06	53.83	54.48	56.31	58.97	61.99	64.89	67.34	69.14	70.21	70.57	70.44	70.05	69.41	68.51	67.34	65.94	64.34	62.59	60.77	63
Abril	60.88	59.34	58.01	56.98	56.34	56.11	56.72	58.42	60.88	63.67	66.37	68.65	70.31	71.31	71.64	71.52	71.17	70.57	69.73	68.65	67.35	65.86	64.24	62.55	64
Mayo	61.72	60.28	59.04	58.09	57.49	57.28	57.84	59.42	61.72	64.32	66.85	68.98	70.55	71.5	71.81	71.7	71.36	70.79	70	68.98	67.76	66.37	64.85	63.27	65
Junio	61.58	60.23	59.08	58.19	57.63	57.44	57.96	59.43	61.58	64.02	66.34	68.25	69.67	70.53	70.81	70.71	70.4	69.89	69.17	68.25	67.16	65.91	64.52	63.03	65
Julio	61.24	60.11	59.14	58.4	57.93	57.77	58.21	59.44	61.23	63.3	65.39	67.26	68.67	69.52	69.81	69.7	69.4	68.88	68.17	67.27	66.19	64.98	63.72	62.46	64
Agosto	60.25	58.79	57.54	56.57	55.97	55.76	56.33	57.93	60.25	62.9	65.41	67.48	69.01	69.94	70.24	70.13	69.8	69.25	68.47	67.48	66.29	64.94	63.44	61.83	64
Septiembre	60.04	58.74	57.64	56.78	56.25	56.07	56.57	57.98	60.04	62.4	64.7	66.68	68.15	69.05	69.35	69.24	68.92	68.38	67.63	66.68	65.55	64.26	62.87	61.44	63
Octubre	59.53	58.14	56.94	56.02	55.44	55.24	55.78	57.31	59.53	62.08	64.49	66.49	67.98	68.89	69.19	69.08	68.76	68.21	67.46	66.49	65.35	64.04	62.59	61.05	63
Noviembre	58.58	57.12	55.86	54.9	54.29	54.08	54.65	56.25	58.58	61.23	63.82	66.02	67.66	68.65	68.98	68.86	68.5	67.91	67.08	66.03	64.76	63.33	61.77	60.16	62
Diciembre	56.53	54.99	53.66	52.64	52	51.78	52.38	54.07	56.53	59.34	62.07	64.4	66.14	67.18	67.53	67.41	67.03	66.4	65.52	64.41	63.07	61.55	59.91	58.2	60
	59	58	57	56	55	55	55	57	59	62	65	67	68	69	70	70	69	69	68	67	65	64	63	61	63

Frio Normal Alerta Peligro Emergencia

Figure 2. Analysis of hourly ITH for semi-cold bioclimate.

In the analysis of the semi-cold, dry bioclimate, the standardized annual data of the meteorological station number 20076, located in the municipality of Asunción Nochixtlán, Oaxaca, were acquired. These data show that the hen will only be in the hygrothermal state of alert 12.50% of the year as shown in Figure 3.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	48.32	45.32	42.73	40.72	39.45	39.01	40.21	43.53	48.32	53.66	58.71	62.87	65.82	67.55	68.11	67.91	67.3	66.27	64.79	62.87	60.51	57.76	54.72	51.52	55
Febrero	50.07	47.11	44.54	42.55	41.29	40.86	42.04	45.33	50.06	55.34	60.38	64.57	67.55	69.28	69.85	69.64	69.03	68	66.51	64.57	62.19	59.42	56.39	53.22	57
Marzo	52.22	49.39	46.94	45.04	43.84	43.43	44.56	47.7	52.21	57.26	62.03	65.95	68.75	70.38	70.91	70.72	70.15	69.17	67.78	65.96	63.73	61.13	58.26	55.24	58
Abril	54.68	51.95	49.59	47.76	46.61	46.21	47.29	50.32	54.67	59.53	64.13	67.9	70.59	72.16	72.67	72.49	71.94	71	69.66	67.91	65.76	63.26	60.5	57.58	61
Mayo	57.1	54.59	52.42	50.73	49.67	49.3	50.3	53.09	57.1	61.58	65.77	69.16	71.58	73	73.46	73.29	72.79	71.95	70.74	69.16	67.23	64.99	62.47	59.78	63
Junio	57.42	55.17	53.24	51.74	50.79	50.47	51.35	53.84	57.41	61.43	65.19	68.25	70.46	71.75	72.18	72.03	71.57	70.79	69.69	68.26	66.51	64.5	62.23	59.82	62
Julio	57.18	55.08	53.26	51.86	50.98	50.67	51.5	53.83	57.18	60.95	64.55	67.54	69.71	70.98	71.4	71.25	70.8	70.03	68.95	67.55	65.84	63.87	61.7	59.44	62
Agosto	57.33	55.15	53.27	51.81	50.89	50.57	51.44	53.85	57.33	61.24	64.91	67.9	70.06	71.33	71.75	71.6	71.15	70.38	69.3	67.9	66.2	64.23	62.03	59.67	62
Septiembre	56.28	54.16	52.33	50.91	50.02	49.72	50.55	52.89	56.28	60.09	63.67	66.61	68.74	69.99	70.41	70.26	69.81	69.06	67.99	66.61	64.94	63.01	60.85	58.56	61
Octubre	54.33	52.05	50.08	48.55	47.59	47.26	48.16	50.69	54.33	58.43	62.34	65.59	67.95	69.33	69.79	69.63	69.13	68.3	67.12	65.6	63.74	61.6	59.25	56.78	59
Noviembre	50.72	48.07	45.79	44.02	42.9	42.52	43.57	46.49	50.71	55.44	59.99	63.81	66.55	68.16	68.68	68.5	67.93	66.97	65.6	63.82	61.64	59.13	56.38	53.54	57
Diciembre	49.22	46.37	43.9	41.99	40.78	40.37	41.5	44.66	49.22	54.31	59.14	63.12	65.97	67.63	68.18	67.98	67.39	66.4	64.98	63.13	60.86	58.23	55.33	52.27	56
	54	51	49	47	46	46	47	50	54	58	63	66	69	70	71	70	70	69	68	66	64	62	59	56	59

Frio Normal Alerta Peligro Emergencia

Figure 3. Analysis of hourly ITH for dry semi-cold bioclimate.

In the Figure 4 shows the analysis of the humid semi-cold bioclimate. Standardized annual data were obtained from the meteorological station number 20308 located in the municipality of San Mateo Río Hondo, Oaxaca, where the hen is found during the hottest hours in an area of ideal comfort, in night hours, the bird is in a cold state which will cause a greater consumption of food.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	52.36	50.29	48.51	47.13	46.27	45.97	46.78	49.06	52.36	56.1	59.64	62.57	64.72	66	66.43	66.28	65.82	65.05	63.96	62.58	60.9	58.98	56.85	54.59	57
Febrero	53.02	50.92	49.11	47.71	46.83	46.53	47.35	49.67	53.02	56.8	60.44	63.5	65.73	67.06	67.5	67.34	66.87	66.07	64.95	63.5	61.76	59.76	57.56	55.28	58
Marzo	54.45	52.41	50.66	49.3	48.45	48.16	48.96	51.2	54.45	58.12	61.65	64.6	66.76	68.05	68.47	68.32	67.86	67.09	66.01	64.61	62.92	60.98	58.85	56.64	59
Abril	56.23	54.29	52.61	51.32	50.5	50.22	50.99	53.13	56.23	59.74	63.05	65.77	67.76	68.95	69.34	69.2	68.78	68.07	67.06	65.78	64.22	62.44	60.44	58.33	61
Mayo	56.57	54.92	53.51	52.42	51.74	51.5	52.14	53.95	56.56	59.54	62.49	65.05	66.93	68.06	68.44	68.31	67.9	67.22	66.27	65.05	63.59	61.91	60.14	58.34	61
Junio	56.5	55.05	53.82	52.87	52.27	52.07	52.63	54.2	56.5	59.13	61.64	63.74	65.31	66.26	66.58	66.47	66.12	65.55	64.75	63.74	62.54	61.18	59.66	58.06	60
Julio	55.56	54.1	52.84	51.88	51.28	51.07	51.64	53.23	55.56	58.23	60.84	63.08	64.76	65.78	66.12	66	65.63	65.02	64.17	63.08	61.8	60.34	58.77	57.15	59
Agosto	55.56	54.14	52.93	52	51.41	51.21	51.76	53.3	55.56	58.14	60.74	63.03	64.75	65.79	66.14	66.01	65.64	65.01	64.14	63.04	61.72	60.23	58.66	57.09	59
Septiembre	55.86	54.45	53.25	52.33	51.74	51.55	52.09	53.62	55.86	58.43	60.95	63.12	64.74	65.73	66.06	65.95	65.59	64.99	64.17	63.12	61.88	60.47	58.95	57.39	59
Octubre	55.28	53.75	52.45	51.44	50.81	50.6	51.19	52.85	55.27	58.04	60.81	63.24	65.05	66.14	66.51	66.38	65.98	65.33	64.41	63.24	61.85	60.27	58.6	56.92	59
Noviembre	54.04	52.23	50.67	49.47	48.71	48.45	49.16	51.15	54.04	57.33	60.51	63.21	65.19	66.39	66.78	66.64	66.21	65.5	64.49	63.21	61.66	59.9	57.99	56	58
Diciembre	52.94	51.02	49.37	48.09	47.29	47.02	47.77	49.88	52.93	56.4	59.82	62.76	64.92	66.21	66.64	66.48	66.02	65.25	64.16	62.76	61.08	59.16	57.1	55	58
	55	53	52	50	50	50	50	52	55	58	61	64	66	67	67	67	67	66	65	64	62	60	59	57	59

Frio Normal Alerta Peligro Emergencia

Figure 4. Analysis of hourly ITH for humid semi-cold bioclimate.

The hourly data of the temperature and humidity index for a temperate bioclimate (Figure 5), here the hygrothermal data were obtained from the meteorological station number 20329 located in the municipality of Oaxaca of Juárez, where the hen will be in a danger zone 39.93% of the year.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	56.92	54.65	52.68	51.16	50.19	49.86	50.77	53.29	56.92	60.99	64.86	68.07	70.37	71.72	72.17	72.01	71.53	70.72	69.57	68.07	66.25	64.13	61.8	59.36	62
Febrero	60.84	58.74	56.93	55.53	54.64	54.33	55.17	57.49	60.83	64.57	68.16	71.18	73.33	74.59	75	74.86	74.41	73.66	72.58	71.18	69.47	67.48	65.31	63.07	66
Marzo	62.44	60.25	58.35	56.88	55.95	55.63	56.51	58.94	62.43	66.33	70	73	75.13	76.36	76.76	76.62	76.19	75.45	74.39	73	71.3	69.31	67.1	64.77	67
Abril	64.87	62.83	61.05	59.67	58.79	58.49	59.31	61.6	64.87	68.51	71.98	74.87	76.91	78.09	78.47	78.33	77.92	77.21	76.2	74.88	73.24	71.32	69.23	67.05	69
Mayo	65.41	63.45	61.75	60.43	59.6	59.31	60.1	62.28	65.41	68.89	72.18	74.86	76.75	77.85	78.21	78.08	77.69	77.04	76.09	74.86	73.34	71.56	69.59	67.5	70
Junio	64.94	63.29	61.87	60.77	60.08	59.84	60.49	62.31	64.94	67.88	70.74	73.17	74.92	75.94	76.28	76.16	75.79	75.18	74.31	73.17	71.79	70.19	68.47	66.7	69
Julio	64.26	62.56	61.09	59.95	59.23	58.99	59.66	61.54	64.25	67.3	70.2	72.6	74.33	75.35	75.68	75.56	75.2	74.59	73.73	72.6	71.24	69.65	67.91	66.08	68
Agosto	64.22	62.58	61.17	60.08	59.39	59.16	59.8	61.61	64.22	67.15	69.95	72.27	73.95	74.95	75.27	75.15	74.8	74.21	73.37	72.28	70.95	69.42	67.73	65.97	68
Septiembre	63.99	62.37	60.98	59.9	59.22	58.99	59.63	61.41	63.99	66.89	69.66	71.97	73.64	74.62	74.95	74.83	74.48	73.89	73.05	71.97	70.65	69.13	67.47	65.72	68
Octubre	63.38	61.69	60.23	59.1	58.39	58.15	58.81	60.68	63.38	66.41	69.31	71.71	73.45	74.48	74.81	74.69	74.33	73.71	72.84	71.72	70.35	68.76	67.02	65.2	67
Noviembre	59.96	57.97	56.26	54.93	54.09	53.8	54.59	56.79	59.95	63.5	66.94	69.85	71.94	73.16	73.57	73.42	72.99	72.25	71.21	69.85	68.2	66.28	64.21	62.08	64
Diciembre	58.23	56.19	54.43	53.07	52.21	51.91	52.72	54.97	58.22	61.88	65.42	68.42	70.58	71.85	72.27	72.12	71.67	70.91	69.83	68.42	66.72	64.74	62.61	60.41	63
	62	61	59	58	57	57	57	59	62	66	69	72	74	75	75	75	75	74	73	72	70	68	67	64	67

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Figure 5. Analysis of hourly ITH for temperate bioclimate.

For the hourly data of the temperature and humidity index of a dry temperate bioclimate (Figure 6). The hygrothermal data were obtained from the meteorological station number 20022 located in the San Bartolo Coyotepec municipality, Oaxaca, where it is observed that the hen will be in a danger zone at 35.76% of the year.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	54.76	52.01	49.64	47.8	46.64	46.24	47.33	50.37	54.75	59.64	64.26	68.06	70.76	72.33	72.84	72.66	72.11	71.16	69.82	68.06	65.9	63.39	60.61	57.68	61
Febrero	56.53	53.79	51.42	49.58	48.42	48.02	49.11	52.15	56.52	61.4	66	69.77	72.45	74.01	74.51	74.33	73.78	72.85	71.52	69.78	67.63	65.14	62.37	59.45	63
Marzo	58.82	56.13	53.79	51.98	50.83	50.44	51.52	54.51	58.81	63.6	68.11	71.79	74.4	75.9	76.39	76.22	75.69	74.79	73.49	71.79	69.7	67.26	64.55	61.68	65
Abril	61.06	58.49	56.26	54.53	53.43	53.05	54.08	56.95	61.06	65.62	69.91	73.41	75.87	77.29	77.75	77.59	77.09	76.24	75.02	73.41	71.43	69.11	66.53	63.8	67
Mayo	62.19	59.76	57.66	56.03	54.99	54.64	55.61	58.31	62.18	66.48	70.52	73.81	76.13	77.46	77.9	77.74	77.27	76.47	75.32	73.81	71.95	69.77	67.34	64.76	67
Junio	62.03	59.91	58.08	56.66	55.76	55.45	56.3	58.65	62.02	65.78	69.4	72.42	74.56	75.81	76.22	76.07	75.63	74.88	73.82	72.42	70.71	68.71	66.53	64.28	67
Julio	60.83	58.74	56.92	55.52	54.64	54.33	55.16	57.49	60.83	64.57	68.11	71.03	73.12	74.34	74.74	74.6	74.17	73.43	72.39	71.03	69.37	67.44	65.31	63.07	65
Agosto	60.84	58.74	56.93	55.53	54.64	54.33	55.17	57.49	60.83	64.57	68.16	71.18	73.33	74.59	75	74.86	74.41	73.66	72.58	71.18	69.47	67.48	65.31	63.07	66
Septiembre	60.76	58.69	56.89	55.5	54.62	54.32	55.15	57.45	60.76	64.46	67.98	70.88	72.95	74.17	74.56	74.42	73.99	73.26	72.23	70.88	69.23	67.32	65.2	62.98	65
Octubre	59.91	57.68	55.74	54.25	53.3	52.98	53.87	56.34	59.91	63.89	67.61	70.61	72.76	74.02	74.43	74.28	73.84	73.09	72.01	70.62	68.91	66.92	64.69	62.29	65
Noviembre	57.52	55.14	53.08	51.48	50.47	50.13	51.07	53.72	57.52	61.77	65.81	69.13	71.5	72.89	73.35	73.18	72.69	71.86	70.68	69.13	67.24	65.05	62.62	60.07	63
Diciembre	55.58	52.94	50.66	48.89	47.77	47.39	48.44	51.37	55.57	60.27	64.72	68.37	70.98	72.5	73	72.82	72.28	71.37	70.07	68.38	66.3	63.88	61.21	58.39	61
	59	57	55	53	52	52	53	55	59	64	68	71	73	75	75	75	74	74	72	71	69	67	64	62	65

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Figure 6. Analysis of hourly ITH for dry temperate bioclimate.

In the Figure 7 shows the hourly data of the temperature and humidity index of a humid temperate bioclimate. The hygrothermal data were obtained from the meteorological station number 20177 located in the municipality of San Ildefonso, Villa Alta, Oaxaca and it is observed that the chicken will be in a danger zone 24.65% of the year.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	57.7	56.39	55.27	54.42	53.88	53.69	54.2	55.62	57.69	60.08	62.48	64.61	66.2	67.17	67.5	67.38	67.03	66.45	65.64	64.61	63.39	62.01	60.56	59.11	61
Febrero	59.55	58.2	57.04	56.15	55.59	55.4	55.92	57.39	59.54	62	64.4	66.46	67.98	68.91	69.22	69.11	68.78	68.22	67.44	66.46	65.28	63.95	62.5	61.01	63
Marzo	62.08	60.53	59.2	58.16	57.51	57.29	57.9	59.61	62.08	64.88	67.57	69.84	71.49	72.48	72.8	72.69	72.33	71.74	70.91	69.84	68.55	67.06	65.44	63.75	66
Abril	64.94	63.29	61.87	60.77	60.08	59.84	60.49	62.31	64.94	67.89	70.64	72.87	74.48	75.42	75.74	75.62	75.29	74.72	73.91	72.87	71.6	70.14	68.48	66.7	69
Mayo	67.42	65.81	64.42	63.34	62.66	62.43	63.07	64.85	67.42	70.29	73.01	75.26	76.86	77.8	78.11	78	77.67	77.11	76.3	75.26	73.98	72.5	70.86	69.14	71
Junio	64.83	63.39	62.14	61.19	60.58	60.37	60.94	62.53	64.83	67.44	69.88	71.87	73.32	74.19	74.47	74.37	74.06	73.54	72.81	71.87	70.73	69.43	67.96	66.39	68
Julio	63.71	62.46	61.39	60.57	60.05	59.87	60.36	61.72	63.7	65.96	68.22	70.2	71.67	72.55	72.85	72.74	72.43	71.9	71.15	70.21	69.07	67.78	66.42	65.05	67
Agosto	63.34	62.04	60.92	60.07	59.53	59.34	59.85	61.27	63.34	65.69	67.98	69.92	71.36	72.22	72.51	72.41	72.1	71.58	70.85	69.92	68.81	67.55	66.17	64.74	66
Septiembre	63.56	62.36	61.33	60.54	60.04	59.87	60.34	61.65	63.55	65.74	67.86	69.68	71.03	71.85	72.12	72.02	71.73	71.24	70.55	69.68	68.64	67.46	66.18	64.86	66
Octubre	62.18	60.92	59.83	59	58.48	58.3	58.79	60.17	62.18	64.49	66.67	68.47	69.81	70.63	70.9	70.8	70.51	70.02	69.34	68.47	67.44	66.27	64.95	63.55	65
Noviembre	59.14	57.76	56.58	55.67	55.09	54.9	55.43	56.94	59.14	61.65	64.1	66.2	67.76	68.7	69.02	68.91	68.57	68	67.21	66.2	65	63.64	62.16	60.64	62
Diciembre	58.82	57.43	56.24	55.33	54.76	54.56	55.1	56.61	58.82	61.34	63.8	65.91	67.47	68.42	68.74	68.63	68.29	67.72	66.92	65.91	64.7	63.33	61.85	60.32	62
	62	61	60	59	58	58	59	60	62	65	67	69	71	72	72	72	72	71	70	69	68	67	65	64	66

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Figure 7. Analysis of hourly ITH for humid temperate bioclimate.

The hourly data of the temperature and humidity index of a warm bioclimate (Figure 8). The hygrothermal data were obtained from the meteorological station number 20149 located in the municipality of Santo Domingo Tehuantepec, Oaxaca in which it is observed that the hen will be in a danger zone 32.99% of the year and in a state of emergency of 20.14%.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	72.44	70.78	69.34	68.23	67.52	67.28	67.94	69.79	72.44	75.37	78.06	80.17	81.65	82.5	82.77	82.68	82.38	81.87	81.14	80.17	78.98	77.57	75.96	74.2	76
Febrero	73.04	71.42	70.01	68.92	68.23	67.99	68.64	70.45	73.04	75.9	78.58	80.74	82.26	83.12	83.4	83.3	83	82.48	81.73	80.75	79.52	78.08	76.47	74.76	76
Marzo	74.74	73.13	71.73	70.64	69.95	69.71	70.36	72.16	74.73	77.58	80.17	82.2	83.61	84.41	84.67	84.58	84.3	83.81	83.12	82.2	81.05	79.7	78.14	76.44	78
Abril	76.55	75.03	73.7	72.67	72.02	71.8	72.41	74.12	76.55	79.25	81.69	83.6	84.93	85.68	85.93	85.84	85.58	85.12	84.47	83.6	82.52	81.25	79.78	78.17	80
Mayo	78.14	76.7	75.45	74.48	73.86	73.65	74.23	75.84	78.14	80.69	83	84.79	86.04	86.76	86.99	86.9	86.66	86.23	85.61	84.79	83.78	82.58	81.19	79.67	81
Junio	77.03	75.66	74.48	73.56	72.98	72.78	73.33	74.85	77.03	79.45	81.65	83.37	84.59	85.28	85.51	85.43	85.18	84.77	84.17	83.37	82.4	81.25	79.92	78.48	80
Julio	77.37	76.08	74.95	74.07	73.52	73.33	73.85	75.3	77.37	79.67	81.88	83.74	85.04	85.79	86.03	85.95	85.69	85.24	84.59	83.74	82.69	81.45	80.12	78.75	80
Agosto	77.79	76.44	75.28	74.37	73.8	73.6	74.14	75.64	77.79	80.17	82.34	84.03	85.22	85.91	86.13	86.05	85.81	85.4	84.81	84.04	83.07	81.95	80.64	79.22	81
Septiembre	76.56	75.19	73.99	73.07	72.48	72.28	72.83	74.36	76.56	79	81.22	82.97	84.19	84.9	85.13	85.05	84.8	84.38	83.77	82.97	81.98	80.82	79.48	78.02	79
Octubre	76.13	74.73	73.51	72.56	71.96	71.76	72.32	73.89	76.13	78.63	80.9	82.69	83.94	84.66	84.89	84.81	84.56	84.13	83.5	82.69	81.68	80.49	79.12	77.63	79
Noviembre	75.22	73.85	72.65	71.73	71.14	70.94	71.49	73.02	75.21	77.64	79.99	81.95	83.34	84.13	84.39	84.3	84.02	83.54	82.86	81.96	80.84	79.54	78.13	76.67	78
Diciembre	73.95	72.46	71.16	70.16	69.52	69.3	69.9	71.56	73.95	76.59	79.07	81.08	82.5	83.31	83.57	83.48	83.19	82.71	82.01	81.09	79.95	78.61	77.12	75.54	77
	76	74	73	72	71	71	72	73	76	78	81	83	84	85	85	85	85	84	83	83	82	80	79	77	79

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Figure 8. Analysis of hourly ITH for warm bioclimate.

In the Figure 9 shows the hourly data of the temperature and humidity index of a dry warm bioclimate. The hygrothermal data were obtained from the meteorological station number 20170 located in the municipality of San Pedro Totolapan, Oaxaca in which it is observed that the hen will be in a danger zone 18.75% of the year and in a state of emergency of 1.74%.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	61.03	58.59	56.47	54.82	53.78	53.43	54.4	57.12	61.02	65.37	69.45	72.79	75.15	76.51	76.95	76.8	76.32	75.5	74.33	72.79	70.9	68.69	66.23	63.63	66
Febrero	63.87	61.59	59.61	58.07	57.09	56.76	57.67	60.22	63.87	67.93	71.67	74.66	76.77	77.99	78.38	78.24	77.81	77.09	76.04	74.67	72.97	70.98	68.73	66.3	69
Marzo	68.7	66.64	64.85	63.47	62.59	62.28	63.11	65.41	68.69	72.33	75.66	78.28	80.11	81.16	81.49	81.37	81.01	80.38	79.48	78.28	76.8	75.05	73.05	70.88	73
Abril	72.2	70.3	68.63	67.34	66.51	66.23	67	69.15	72.2	75.56	78.68	81.17	82.9	83.87	84.18	84.07	83.73	83.15	82.3	81.18	79.77	78.1	76.23	74.22	76
Mayo	72.03	70.05	68.33	66.99	66.14	65.85	66.65	68.86	72.02	75.5	78.71	81.28	83.05	84.05	84.36	84.25	83.91	83.31	82.44	81.28	79.83	78.12	76.18	74.11	76
Junio	69.71	67.84	66.21	64.95	64.15	63.87	64.62	66.71	69.7	73	76.15	78.74	80.55	81.58	81.91	81.8	81.44	80.82	79.92	78.74	77.28	75.55	73.66	71.69	74
Julio	68.83	66.97	65.35	64.09	63.3	63.02	63.77	65.85	68.83	72.13	75.27	77.88	79.7	80.74	81.08	80.96	80.59	79.97	79.07	77.88	76.4	74.67	72.78	70.81	73
Agosto	69.66	67.87	66.32	65.11	64.35	64.08	64.8	66.8	69.66	72.83	75.79	78.2	79.89	80.86	81.17	81.06	80.72	80.14	79.31	78.2	76.84	75.24	73.45	71.56	73
Septiembre	69.94	68.18	66.64	65.45	64.7	64.44	65.15	67.12	69.94	73.07	75.95	78.23	79.83	80.75	81.05	80.94	80.62	80.07	79.27	78.23	76.94	75.42	73.7	71.82	74
Octubre	68.3	66.44	64.83	63.58	62.79	62.52	63.26	65.33	68.3	71.59	74.62	77.03	78.73	79.71	80.02	79.91	79.57	78.98	78.14	77.03	75.67	74.07	72.25	70.27	72
Noviembre	64.5	62.37	60.51	59.07	58.16	57.85	58.71	61.09	64.5	68.29	71.85	74.76	76.8	77.98	78.36	78.23	77.81	77.11	76.09	74.76	73.11	71.19	69.04	66.78	69
Diciembre	62.09	59.78	57.77	56.22	55.24	54.9	55.82	58.39	62.08	66.19	70.06	73.21	75.44	76.73	77.15	77	76.55	75.78	74.67	73.21	71.43	69.33	67.01	64.55	67
	68	66	64	62	62	61	62	64	68	71	74	77	79	80	81	80	80	79	78	77	76	74	72	70	72

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Figure 9. Schedule ITH analysis for dry warm bioclimate.

The hourly data of the temperature and humidity index of a humid warm bioclimate is shown in Figure 10. The hygrothermal data were obtained from the meteorological station number 20048 located in the municipality of Juchitán de Zaragoza, Oaxaca where it is observed that the hen will be in a danger zone 38.54% of the year and in a state of emergency 4.86%.

MES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	PRO
Enero	71.6	70.41	69.4	68.61	68.11	67.94	68.41	69.71	71.6	73.73	75.7	77.29	78.45	79.13	79.36	79.28	79.03	78.62	78.04	77.29	76.38	75.34	74.15	72.87	74
Febrero	72.38	71.1	70	69.14	68.6	68.42	68.92	70.34	72.38	74.67	76.84	78.64	79.93	80.69	80.94	80.85	80.58	80.13	79.48	78.64	77.62	76.43	75.12	73.75	75
Marzo	74.01	72.79	71.73	70.91	70.4	70.22	70.7	72.06	74	76.18	78.31	80.13	81.43	82.19	82.43	82.35	82.08	81.62	80.97	80.13	79.1	77.89	76.61	75.31	77
Abril	76.75	75.52	74.45	73.62	73.1	72.92	73.41	74.78	76.75	78.94	81.01	82.7	83.9	84.59	84.82	84.74	84.49	84.08	83.48	82.7	81.74	80.62	79.38	78.06	79
Mayo	78.22	77.05	76.03	75.24	74.74	74.57	75.04	76.35	78.22	80.31	82.28	83.89	85.03	85.69	85.91	85.83	85.6	85.2	84.63	83.89	82.98	81.91	80.72	79.47	81
Junio	77.11	76.01	75.06	74.33	73.87	73.71	74.14	75.36	77.11	79.08	80.89	82.32	83.35	83.95	84.15	84.08	83.86	83.5	82.99	82.32	81.51	80.56	79.47	78.29	79
Julio	76.44	75.43	74.55	73.88	73.45	73.3	73.7	74.82	76.43	78.24	80.04	81.59	82.72	83.38	83.6	83.52	83.28	82.89	82.33	81.6	80.71	79.69	78.6	77.52	79
Agosto	76.64	75.53	74.58	73.83	73.37	73.21	73.65	74.87	76.64	78.63	80.46	81.91	82.95	83.56	83.76	83.69	83.47	83.1	82.58	81.91	81.08	80.13	79.03	77.83	79
Septiembre	76.02	74.97	74.06	73.36	72.92	72.77	73.18	74.34	76.01	77.9	79.69	81.19	82.27	82.91	83.12	83.04	82.81	82.43	81.89	81.19	80.34	79.35	78.27	77.14	78
Octubre	75.05	74.05	73.19	72.52	72.1	71.96	72.35	73.46	75.05	76.85	78.58	80.03	81.09	81.72	81.92	81.85	81.63	81.25	80.72	80.03	79.21	78.26	77.21	76.13	77
Noviembre	74.38	73.36	72.49	71.81	71.39	71.24	71.64	72.76	74.37	76.21	77.97	79.45	80.54	81.18	81.4	81.32	81.09	80.7	80.16	79.45	78.61	77.64	76.58	75.47	77
Diciembre	72.67	71.62	70.72	70.03	69.59	69.44	69.85	71	72.67	74.56	76.39	77.94	79.07	79.75	79.98	79.9	79.65	79.25	78.67	77.94	77.06	76.04	74.94	73.8	75
	75	74	73	72	72	72	72	73	75	77	79	81	82	82	83	83	82	82	81	81	80	79	78	76	78

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Figure 10. Analysis of hourly ITH for humid warm bioclimate.

In the Table 4 presents a summary of the statistical percentages that will be given in each of the bioclimates during the year based on the standard data of 1982-2010 provided by the meteorological stations of the National Water Commission (CONAGUA). It is observed that the bioclimates in which the bird will have greater development difficulty, loss of body mass and in egg production, correspond mainly to warm bioclimates and to a lesser extent to the hot, humid and warm dry bioclimate.

Table 4. Statistical percentage of ITH conditions for laying hens in the 9 bioclimates present in the state of Oaxaca.

Bioclimate	State	Cold (%)	Normal (%)	Alert (%)	Hazard (%)	Emergency (%)	Total (%)
Semicold		49.31	43.06	7.64	0	0	100
Semicold dry		57.29	30.21	12.50	0	0	100
Semicold humid		65.28	34.2	0	0	0	100
Tempered		34.72	25.35	39.93	0	0	100
Dry tempering		43.40	20.83	35.76	0	0	100
Warm wet		36.11	39.24	24.65	0	0	100
Warm		0.00	5.21	41.67	32.99	20.14	100
Warm dry		4.51	18.75	47.22	27.08	2.4	100
Warm wet		0.00	4.86	51.74	38.54	4.86	100

In all the regions of the state of Oaxaca or anywhere else in Mexico, it is enough to find the bioclimate of the desired site in order to know how the bird would behave in that area, in case of establishing a poultry farm. In addition, with the ITH schedules, a prediction of the losses of egg production and weight of hens can be made in each of the existing bioclimates in Mexico using the mathematical model proposed by St-Pierre *et al*. (2003). Something similar was done by Guevara *et al.* (2013) for ITH conditions in livestock production, in a province of Venezuela.

Conclusions

In the present work a hygrothermal comfort zone is defined for laying hens that ranges between 18-22 °C and 60-70% relative humidity. This comfort zone will be used to carry out the design of a biospace to obtain a better egg production. The hourly analyzes of the comfort zone in which the hens are located in each bioclimate, will allow to determine the strategies to obtain a better production. It is also observed that the hen will be in danger and alert areas in greater percentage in the warm bioclimates and without a biospace that provides the conditions of adequate hygrothermal comfort will see a considerable drop in its production. In bioclimates with cold conditions there will be a better consumption of food of the bird in order to maintain its body temperature, in addition to a better conversion between consumed food and egg mass Craig (2002).

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