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# Determination of Hidden Condensation on The Exterior Walls of The Poultry Farm Using Finite Element Method

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**Abstract:** The knowledge of temperature distribution within a wall is important to determine where condensation may occur and what precautions to take. This study used the finite element method to simulate the temperature distributions in different types of walls (solid brick, Ytong, concrete wall) for poultry farms in cities in different climatic regions of Turkey (1st zone: Antalya, 2nd zone: Samsun, 3rd zone: Ankara and 4th zone: Erzurum) and identify on which surfaces condensation could occur. The study assumed an indoor temperature of 20 ºC, a relative humidity of 60%, and a dew point temperature of 12.04 ºC. According to the results, hidden condensation was more common in Ankara and Erzurum, where the outdoor temperatures (6.30 and -0.50 ºC, respectively) are colder than in the other two cities. Therefore, it would be appropriate to install vapor barrier materials on the warm side of the walls to prevent hidden condensation.

**Keywords:** Climate, condensation, insulation, numerical analysis, temperature.

# Sonlu Elemanlar Yöntemini Kullanarak Kümes Dış Duvarlarındaki Gizli Yoğunlaşmanın Belirlenmesi

**Öz:** Duvar içindeki sıcaklık dağılımının bilinmesi, yoğunlaşmanın nerede olabileceğinin ve dolayısıyla nasıl önlem alınabileceğinin tespiti açısından önemlidir. Bu çalışmada, sonlu elemanlar yöntemi kullanılarak Türkiye'nin farklı iklimsel bölgelerindeki şehirler (1. bölge: Antalya, 2. bölge: Samsun, 3. bölge: Ankara ve 4. bölge: Erzurum) için kümeslerdeki farklı duvar tiplerindeki (tuğla, Ytong ve beton duvar) sıcaklık dağılımları belirlenerek, hangi yüzeylerde yoğunlaşma olabileceği tespit edilmiştir. Çalışmada iç ortam sıcaklığının 20 ºC, bağıl nemin %60 ve çiğ noktası sıcaklığının 12.04 ºC olduğu varsayılmıştır. Elde edilen sonuçlara göre dış ortam sıcaklıkları diğer şehirlere göre daha soğuk olan (6.30 ve -0.50 ºC) Ankara ve Erzurum illerinde gizli yoğunlaşma daha yoğun olarak görülmüştür. Gizli yoğunlaşmayı önlemek için duvarın sıcak tarafına buhar kesici malzemelerin yerleştirilmesi uygun olacaktır.

**Anahtar Kelimeler:** İklim**,** yoğunlaşma, yalıtım, sayısal analiz, sıcaklık.

## 1. Introduction

Insulation plays an important role in providing effective environmental conditions in the poultry building (Küçüktopcu and Cemek, 2018; Küçüktopcu and Cemek, 2019). In addition to reducing heat loss in the winter and preventing excessive heating during the summer, insulation assists in preventing moisture condensation on the surfaces of building elements and in adjusting the temperature values within the building (Olgun et al., 2007).

Moisture condensation in building materials occurs when the surface temperature of the building material in contact with the air is below the dew point temperature of the air. The subsequent accumulation of moisture causes rot and rusting on building elements and decreases the insulating value of the building material. Moisture condensation also has a detrimental effect on the health and production of animals, as increased moisture inside the building causes the litter to become wet (Lindley and Whitaker, 1996).

Moisture condensation is visible on both the exterior and interior surfaces of the building elements. As the latter condition – referred to as hidden condensation – occurs within the building element, it cannot be detected in time. If no action is taken, the damage to the building components exacerbates (Öztürk, 2003; Olgun, 2011).

The objective of this study was to determine the building material on which hidden condensation could occur. To accomplish this, representative cities from different climatic regions of Turkey were chosen, and the temperature distributions within the wall for poultry buildings were simulated using the finite element method for various building element combinations.

## 2. Material and Method

In this study, four different provinces were selected as representative from four different degree day regions (heating energy values at 1st zone: 19.2-56.7 kWh/m²-year, 2nd zone: 38.4-97.9 kWh/m²-year, 3rd zone: 51.7-116.5 kWh/m²-year, and 4th zone: 67.3-137.6 kWh/m²-year) of Turkey (TS 825, 2008). The climatic characteristics of the selected provinces are given in Table 1. Three different wall combinations were used as materials in this study (Table 2).

**Table 1.** Climatic characteristics of selected provinces
***Çizelge 1.*** *Seçilen illerin iklim özellikleri*

| Climatic Zones | City | Latitude (°) | Longitude (°) | Average lowest temperature (°C) |
|---|---|---|---|---|
| 1st zone | Antalya | 30.6868 | 36.8940 | 13.80 |
| 2nd zone | Samsun | 36.3234 | 41.2871 | 11.10 |
| 3rd zone | Ankara | 32.8496 | 39.9347 | 6.30 |
| 4th zone | Erzurum | 41.2709 | 39.9051 | -0.50 |

**Table 2.** Wall types and thermal resistance values
***Çizelge 2.*** *Duvar tipleri ve ısıl direnç değerleri*

| Wall combinations | Material | Thickness (m) | Resistance ($m^2h$/Kcal) |
|---|---|---|---|
| **Combination I** | Cement plaster (outside wall) | 0.030 | 0.025 |
| | Solid brick | 0.220 | 0.293 |
| | Lime plaster (inside wall) | 0.020 | 0.027 |
| | | | |
| **Combination II** | Cement plaster (outside wall) | 0.030 | 0.025 |
| | Ytong | 0.200 | 1.111 |
| | Lime plaster (inside wall) | 0.020 | 0.027 |
| | | | |
| **Combination III** | Cement plaster (outside wall) | 0.020 | 0.017 |
| | Concrete wall | 0.100 | 0.077 |
| | Cement plaster (inside wall) | 0.020 | 0.017 |

The outdoor temperature values were considered for the annual average lower temperature values of the chosen provinces (MGM 2021). It is recommended that the optimum indoor temperature for chickens be varied between 18-27 ºC and relative humidity between 50-70% (Holik, 2009; Baracho et al., 2011). The study assumed an indoor temperature of 20 ºC and a relative humidity of 60%.

### 2.1. Finite element method

Finite element method is a widely used numerical solution technique for a variety of boundary value problems in engineering. In this method, a complex model is divided into a certain number of small and interconnected sub-regions (elements) called finite elements and nodes. In the next step, a function is determined to represent the approximate solution of an element, and the equation is developed. To solve the problem, the elements are integrated, and boundary conditions, initial conditions, and structural conditions such as loads or heat for heat conduction problems are applied. A solution is obtained through simultaneous or successive linear or non-linear equations, and then the results are obtained if the simulation converges to a certain value (Moaveni, 2011; Whiteley, 2014; Rao, 2017).

In this study, a model with five elements and six nodes was used to simulate the temperature distribution within the wall (Figure 1).

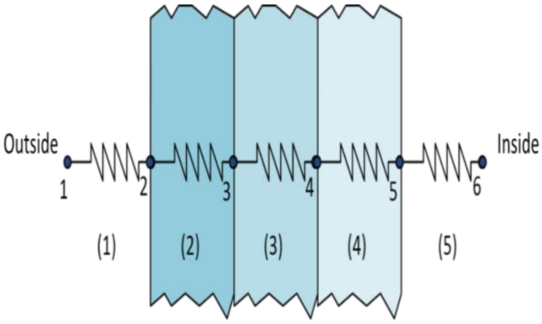


**Figure 1.** Finite element model of the wall
***Şekil 1.*** *Duvarın sonlu eleman modeli*

**2.2. Heat transfer equations and finite element formulation**

Heat transfer is the energy transfer due to temperature differences. Energy is transmitted from the hot surface to the cold surface due to molecular motions (Figure 2).

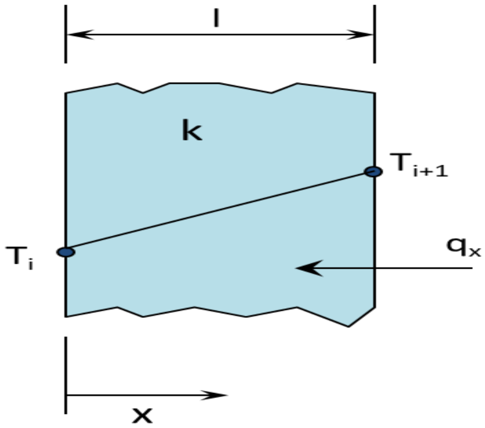


**Figure 2.** Heat transfer by conduction
***Şekil 2****. İletim yoluyla ısı transferi*

The heat transfer rate is given by Fourier's law:

$$q_x = -kA\frac{dT}{dX} \tag{1}$$

where $q_x$ is the heat transfer rate (W), $k$ is the thermal conductivity of the medium (W/mK), $A$ is the surface area perpendicular to the heat transfer ($m^2$), and $dT/dX$ is the temperature gradient. If the equation is rearranged depending on the length of the element ($l$) and the temperatures between the nodes ($T_i$ and $T_{i+1}$);

$$q = \frac{kA(T_{i+1} - T_i)}{l} \tag{2}$$

$$U = \frac{k}{l} \tag{3}$$

$$q = UA(T_{i+1} - T_i) \tag{4}$$

Convection heat transfer occurs when a fluid in motion comes into contact with a solid surface whose temperature is different from its temperature. The amount of heat transferred per unit time via convection is calculated using Newton's law of cooling.

$$q = hA(T_s - T_f) \tag{5}$$

where $h$ is the heat transfer coefficient ($W/m^2K$), $T_s$ is the surface temperature (K), and $T_f$ is the fluid temperature (K).

In steady-state heat conduction, the heat transferred to a surface must equal the heat transfer by convection.

$$-kA\frac{\partial T}{\partial X} = hA(T_s - T_f) \tag{6}$$

When this principle is applied to the wall, the following equations are obtained.

$$\begin{aligned} U_2A(T_3 - T_2) &= U_1A(T_2 - T_1) \\ U_3A(T_4 - T_3) &= U_2A(T_3 - T_2) \\ U_4A(T_5 - T_4) &= U_3A(T_4 - T_3) \\ U_5A(T_6 - T_5) &= U_4A(T_5 - T_4) \end{aligned} \tag{7}$$

Once the equations are created, and the necessary adjustments are made, the problem will take on the matrix form shown below. The temperature distribution along the thickness of the wall can be determined by solving the matrix after entering the boundary conditions.

$$A\begin{bmatrix} U_1+U_2 & -U_2 & 0 & 0 \\ -U_2 & U_2+U_3 & -U_3 & 0 \\ 0 & -U_3 & U_3+U_4 & -U_4 \\ 0 & 0 & -U_4 & U_4+U_5 \end{bmatrix}\begin{Bmatrix} T_2 \\ T_3 \\ T_4 \\ T_5 \end{Bmatrix} = \begin{Bmatrix} U_1.A.T_{out} \\ 0 \\ 0 \\ U_5.A.T_{in} \end{Bmatrix} \tag{8}$$

**3. Results and Discussion**

Moisture condensation on the surfaces of building elements is determined by the surface temperature of the building elements and the dew point temperature of the surrounding air. The study used an indoor temperature of 20 ºC, a relative humidity of 60%, and a dew point temperature ($T_{dew}$) of 12.04 ºC. Accordingly, moisture condensation will occur on surfaces with a surface temperature lower than 12.04 ºC. To determine the surfaces upon which moisture condensation can occur, the temperature values at the nodes were determined using the finite element method (Table 3). As indicated in the table, the T1 value represents the annual average lowest outdoor temperatures of the selected cities, while the T6 indicates the indoor temperature.

**Table 3.** Node temperature values (°C) according to selected provinces and wall types
***Çizelge 3.*** *Seçilen illere ve duvar tiplerine göre düğüm noktaları sıcaklık değerleri (°C)*

| Wall combinations | Nodes | Antalya | Samsun | Ankara | Erzurum |
|---|---|---|---|---|---|
| Combination I | $T_1$ | 13.80 | 11.10 | 6.30 | -0.50 |
| | $T_2$ | 13.91 | 11.25 | 6.54 | -0.14 |
| | $T_3$ | 16.49 | 14.96 | 12.24 | 8.38 |
| | $T_4$ | 18.10 | 17.27 | 15.80 | 13.72 |
| | $T_5$ | 19.69 | 19.56 | 19.32 | 18.98 |
| | $T_6$ | 20.00 | 20.00 | 20.00 | 20.00 |
| | $T_{dew}$ | 12.04 | 12.04 | 12.04 | 12.04 |
| | | | | | |
| Combination II | $T_1$ | 13.80 | 11.10 | 6.30 | -0.50 |
| | $T_2$ | 13.93 | 11.29 | 6.60 | -0.06 |
| | $T_3$ | 17.15 | 15.91 | 13.70 | 10.58 |
| | $T_4$ | 17.63 | 16.60 | 14.77 | 12.17 |
| | $T_5$ | 19.62 | 19.45 | 19.15 | 18.73 |
| | $T_6$ | 20.00 | 20.00 | 20.00 | 20.00 |
| | $T_{dew}$ | 12.04 | 12.04 | 12.04 | 12.04 |
| | | | | | |
| Combination III | $T_1$ | 13.80 | 11.10 | 6.30 | -0.50 |
| | $T_2$ | 13.88 | 11.22 | 6.48 | -0.23 |
| | $T_3$ | 15.78 | 13.94 | 10.67 | 6.04 |
| | $T_4$ | 17.87 | 16.95 | 15.30 | 12.96 |
| | $T_5$ | 19.77 | 19.67 | 19.49 | 19.24 |
| | $T_6$ | 20.00 | 20.00 | 20.00 | 20.00 |
| | $T_{dew}$ | 12.04 | 12.04 | 12.04 | 12.04 |

When all wall combinations are considered for Antalya, located in the first-degree day region, no surface temperature is lower than the dew point temperature. Therefore, no moisture condensation occurred on any surface for Antalya.

In Samsun, located in the second-degree day region, the vapor moisture in the air will condense anywhere between nodes 2 and 3 in all wall combinations.

In Ankara, located in the third-degree day region, moisture condensation will occur on the surfaces between nodes 2 and 3 for the first and second wall combinations and between nodes 3 and 4 for the third wall combinations.

In Erzurum, which has the coldest outdoor temperature among the selected provinces, moisture condensation will occur between nodes 3 and 4 in all wall combinations.

As the results demonstrate, the interior surface temperatures of the building elements remain lower than the ambient temperature due to contact with the cold outside air in regions with low outdoor temperatures. Moisture condensation occurs when the surface temperature of a building element falls below the dew point temperature. As the outdoor temperature decreases, the areas close to the indoor surfaces exhibit higher levels of moisture condensation; thus, insulation and vapor barrier are more important in colder regions (Al-Homoud, 2005; Craven and Garber-Slaght, 2014).

Moisture-repellent materials should be installed on the warm side of the wall to prevent the transferal of moisture through the structure's elements. The most suitable place for this is recommended under the interior plaster and above the insulation material (Öztürk, 2003).

## 4. Conclusion

Since moisture condensation formed within building elements is invisible to the naked eye, it causes more serious problems than moisture condensation on the surface. In this study, the finite element method was used to determine the locations of hidden condensation in various wall types for representative cities in Turkey's different climatic regions.

Consequently, it has been determined that the hidden concentration is more intense in the provinces of Ankara and Erzurum, which are located in the third and fourth climatic zones, respectively.

To avoid condensation in the building elements and to minimize potential damage, especially in cold climates, air barriers and vapor retarders should be installed on the warm side of the wall.

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