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# INVESTIGATION OF OPTIMUM AIR GAP THICKNESS FOR WINDOWS IN PROVINCES OF THE AEGEAN REGION

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**Abstract**

*In this study the effects of varying the air gap on insulation of window which is air layer between two glass plates in a vertical position starting from 1 mm to 280 mm are researched for eight provinces in the Aegean region. Optimum air gap for windows is enhanced based on the results of this study. With this approach, optimum air gap are calculated as follows: 14 mm for İzmir, 13 mm for Denizli, 12.5 mm for Uşak, 13.4 mm for three provinces (Aydın, Manisa, Muğla) with the same exterior temperature, and 12.2 mm for two provinces (Afyon, Kütahya). This study introduces optimum air gap approach for each province in the Aegean region.*
**Keywords:** *Air gap, Insulation on windows, Province based optimum air layer thickness.*

# EGE BÖLGESİNDEKİ İLLERDE PENCERELER İÇİN OPTİMUM HAVA TABAKASI KALINLIĞININ ARAŞTIRILMASI

**Özet**

*Bu çalışmada Ege Bölgesi'ndeki sekiz (Manisa, İzmir, Kütahya, Uşak, Afyon, Aydın, Denizli, Muğla) il için düşey konumda iki cam plaka arasındaki hava tabakası 1 mm'den başlayıp 280 mm'ye kadar hava boşluğunun penceredeki yalıtıma etkileri araştırılmıştır. Araştırma sonuçlarına göre; Ege Bölgesi'ndeki iller için pencerelerde optimum hava boşluğu yaklaşımı getirilmiştir. Bu yaklaşımla İzmir'de 14 mm, Denizli'de 13 mm, Uşak'ta 12,5 mm ve dış hava sıcaklığı aynı olan üç ilde (Aydın, Manisa, Muğla) 13,4 mm ve iki ilde (Afyon, Kütahya) 12,2 mm olarak optimum hava tabakası kalınlığı hesaplanmıştır. Bu çalışma ile literatüre Ege Bölgesi'ndeki her il için optimum hava tabakası kalınlığı yaklaşımı getirilmiştir.*
**Anahtar Kelimeler:** *Hava boşluğu, Pencerelerde yalıtım, İl bazında optimum hava tabakası.*

## 1 Introduction

The continuous increases in global population and technological advances developing at dizzying speed have continuously increased the demand for energy. Globally energy is largely obtained from fossil fuel sources and may lead to exhaustion of all fossil fuels in the near future. Demand for fossil energy is higher than the rate of formation of fossil fuels. This situation has caused pollution of air in the atmosphere and global warming of the earth.

There is more than 750 billion tons of carbon dioxide in the atmosphere. Due to respiration of plants, animals and soil at the surface, use of fossil fuels, deforestation and ocean-atmosphere interactions, each year nearly 207 billion tons of carbon dioxide are released into the atmosphere. However, photosynthesis by land plants, and again ocean-atmosphere interaction sequester nearly 205 billion tons of carbon dioxide from the atmosphere each year. In this situation, nearly 3 billion tons of carbon dioxide is added to the atmosphere each year. This is equivalent to the amount of carbon dioxide released into the atmosphere due to the use of fossil fuels by humans. The fossil fuel reserves globally have caused carbon dioxide levels in the atmosphere to increase 5-10 times and disrupted this balance [1].

In the first standards and directives for efficient use of energy in buildings, attempts were made to reduce heat losses to minimal levels. Later in the process, productivity of heating, cooling and air conditioning systems became the focus. Since the beginning of the 2000's with the awareness that current resources will not be sufficient for future generations, the “sustainability” concept has led to attempts to reduce fossil fuel use to the minimum possible [2].

Since 2012 sectorial distribution of energy consumption in Turkey is; industry, residential and services 26%, transportation 17%, conversion power plants 26%, agriculture 3% and other 2% [3].

Since 14 June 2000, all licensed buildings to be built in our country require mandatory insulation of outer walls as a compulsory standard for buildings according to TS 825. As a result of government incentives for insulation, while energy consumption for residential and services was 30% in 2007, it dropped to 26% in 2012.

It appears that energy consumption according to sectoral distribution is highest for residences. As a result, insulation of outer walls, flooring, roofs and windows of buildings to reduce building heat loss has become important in leading precautions against global warming.

The importance of heat insulation is based on two main concepts of energy and the environment. To these we can add healthy and comfortable living areas. Energy is not just important to us, but to other countries and is a strategic macro concept. In our country, the reality is that we are not very rich in terms of energy resources. Up to 60-65% of energy requirements are imported [4, 5].

When heat insulation is correctly used, it is a combination of material or materials that reduce the speed of heat flow through conduction, convection and radiation. Insulating materials reduce heat flow speed from exterior to interior of buildings or interior to exterior of buildings due to high thermal resistance properties. Insulating materials show resistance to heat flow and prevent heat transfer by convection due to countless microscopic enclosed air cells (preventing movement of air within them). The heat resistance is not due to the insulating material but to the air cells contained within the insulating material. Insulating material with small cell size (with enclosed cellular structure) reduces the effect of radiation at the same time. Additionally, reducing the cell sizes within insulating material increases density, and generally increases heat transfer by conduction. Typically dead air cell insulating material does not exceed the heat resistance shown by stagnant air [6].

Buildings lose heat at a rate of 40% from outer walls, 30% from windows, 17% from doors, 7% from roofs and 6% from flooring [7]. To reduce heat losses and gains from windows, insulation should use a material not affecting transparency. Air is transparent and due to lower heat conduction resistance compared to the majority of other insulating materials, is used as an insulating material for windows. Insulation of windows is performed by trapping air sealed between two glass panes.

This study is based on the approach to air gap thickness for windows in some cities, published by Erturk et al. [8], used to research the effects of window insulation with air gaps from 1 mm to 280 mm between two vertical glass panes applied to eight cities in the Aegean region (Manisa, İzmir, Kütahya, Uşak, Afyon, Aydın, Denizli, Muğla).

## 2 Calculation Method

This study used exterior air temperatures for the cities of Manisa, İzmir, Kütahya, Uşak, Afyon, Aydın, Denizli, and Muğla, based on TS 825 to research the effect of different air gap thicknesses for each city on total heat transfer coefficients and heat loss. Additionally the optimum air gap thickness was calculated for each city in the Aegean region.

The preparation rules given below should be followed: It is recommended that you either use the template or stick to a sample file in order to meet the specifications for the format of MJST papers.

### 2.1 Heat Transfer through Vertically Enclosed Gaps

In vertically enclosed gaps, horizontal surfaces are adiabatic as vertical surfaces are heat or cool. Fluid motion rises along the hot surface of the fluid and decreases along the cold surface completing a cellular circulatory motion. When $\mathrm{Ra} \leq 10^3$, the flow due to buoyancy is weak and heat transfer occurs by conduction through the fluid. As a result in accordance with Fourier’s law, the Nusselt number $\mathrm{Nu} = 1$. As the Rayleigh number increases, cellular flow increases and concentrates as thin boundary layers on the side surfaces. The central region remains stagnant; however, additional cells may form at corners and the ends of boundary layers on side surfaces may be turbulent [9].

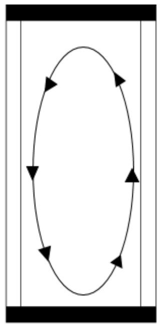

Figure 1. Cellular flow in enclosed gaps with different surface temperatures.

When the Rayleigh number is < 1708 as buoyancy cannot overcome fluid resistance, heat transfer occurs by conduction. In situations where the Rayleigh number is > 1708, conditions are thermally unstable and buoyancy overcomes fluid resistance. When the Rayleigh number is in the interval $1708 < Ra \leq 5 \times 10^4$ fluid motion begins as regular circulating cells in a certain region and at larger Rayleigh numbers, the air layer does not behave as a solid object but as a fluid. As the cellular structure is disrupted fluid motion is turbulent [10].

To identify the interval where heat transfer by convection begins, one of the parameters used is the Rayleigh number. The Rayleigh number (Ra) for ideal fluids is given in Equation (1), while the expansion coefficient (β) is given in Equations (2)-(3).

$$Ra = \frac{g \times \beta \times (T_s - T_\infty) \times L^3}{\vartheta^2} \times Pr \tag{1}$$

$$\beta = \frac{1}{T_{film}} \tag{2}$$

$$T_{film} = \frac{T_1 + T_2}{2} \tag{3}$$

One of the parameters used to determine the interval when heat transfer by convection begins is the Nusselt number. The Nusselt number for vertically enclosed spaces and the convection coefficient used for total heat transfer calculations are given in Equations (4)-(5). The heat transfer by convection is given in equation 8.

$$Nu = 0{,}42 \times {Ra_L}^{1/4} \times Pr^{0{,}012} \times \left(\frac{H}{L_h}\right)^{-0{,}3} \tag{4}$$

$$h_h = \frac{k_{air} \times Nu}{L_h} \tag{5}$$

### 2.2 Total Heat Transfer between Two Vertical Glass Panes

Heat loss from windows according to fluid type occurs through conduction, convection and radiation. In this study, calculations are performed according to optimum air gap thickness on the optimum air gap. The heat transfer below optimum air gap for windows (Qopt) is given in Equation (6), with the total heat transfer coefficient below optimum air gap ($k_{T_1}$) given in Equation (7) and total heat transfer below optimum air gap ($Q_{T_1}$) given in Equation (8).

$$Q_{opt} = k_{T_1}.A_{window}.(T_1 - T_2) \tag{6}$$

$$\frac{1}{k_{T_1}} = \frac{1}{h_{indoor}} + \frac{l_g}{k_g} + \frac{l_{air}}{k_{air}} + \frac{l_g}{k_g} + \frac{1}{h_{outdoor}} \tag{7}$$

$$Q_{T_1} = Q_{opt} + Q_{convection} \tag{8}$$

Increasing the optimum air gap between two vertical glass panes increases the fluid behavior in the air gap and as a result increases the Nu and Ra numbers. This situation transforms heat transfer by conduction into heat transfer by convection. The heat convection coefficient according to air gap thickness is found using Equations (4)-(5) and regulated in Equation (9). Heat transfer in windows above optimum air gap thickness (QTa) is given in Equation (9) with total heat transfer coefficient above optimum air gap ($k_{t_2}$) given in Equation (10).

$$Q_{Ta} = k_{t_2}.A_{window}.(T_1 - T_2) \tag{9}$$

$$\frac{1}{k_{t_2}} = \frac{1}{h_{indoor}} + \frac{l_g}{k_g} + \frac{1}{h_{air}} + \frac{l_g}{k_g} + \frac{1}{h_{outdoor}} \tag{10}$$

Heat transfer by radiation for windows is given in Equation (11), with diffusivity in vertical panes ($\varepsilon$) given in Equation (12) and total heat transfer in air gaps above optimum air gap ($Q_{T_2}$) given in Equation (13).

$$Q_{radiation} = \varepsilon.\sigma.A_W.(T_1{}^4 - T_2{}^4) \tag{11}$$

$$\varepsilon = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \tag{12}$$

$$Q_{T_2} = Q_{Ta} + Q_{radiation} \tag{13}$$

## 3 Analysis

In eight cities in the Aegean region, different thicknesses of air gap have been separately analyzed for effects on total heat transfer coefficients and heat loss in each city according to exterior air temperatures in TS 825 with window height of 120 cm and width of 50 cm. The thermo-physical properties of air used in the analyses are given in Table 1, with analysis results for Mugla given in Table 2. Studies were completed for all eight cities, with each province shown as a separate figure, not in tables, to prevent extension of the text.

### 3.1 Research into Total Heat Transfer Coefficient and Effect on Heat Transfer of Air Gap Thickness

The insulation effect and optimum air gap thickness for windows in Manisa, İzmir, Kütahya, Uşak, Afyon, Aydın, Denizli, and Muğla with vertical position and two 0.6 m² glass panes enclosing an air gap from 1 mm to 280 mm thick was researched.

Table 1. Thermo-physical properties of air [11].

| Cities | $T_1$ °C | $T_2$ °C | $\beta$ °$K$ | $\vartheta$ $m^2/s$ | K $W/m^2K$ | Pr (-) |
|---|---|---|---|---|---|---|
| Manisa | 20 | -3 | 0.0035 | 1.407 | 0.0247 | 0.71791 |
| İzmir | 20 | 0 | 0.0035 | 1.420 | 0.0248 | 0.71759 |
| Kütahya | 20 | -12 | 0.0036 | 1.367 | 0.0243 | 0.71888 |
| Uşak | 20 | -9 | 0.0035 | 1.381 | 0.0244 | 0.71855 |
| Afyon | 20 | -12 | 0.0036 | 1.367 | 0.0243 | 0.71888 |
| Aydın | 20 | -3 | 0.0035 | 1.407 | 0.0247 | 0.71791 |
| Denizli | 20 | -6 | 0.0035 | 1.394 | 0.0246 | 0.71823 |
| Muğla | 20 | -3 | 0.0035 | 1.407 | 0.0247 | 0.71791 |

### 3.2 Determination of Optimum Air Gap Thickness for Each Province

The optimum air gaps for eight cities in the Aegean region are given in Table 3 and shown in Figures 2-9. In Table 2, for 1 mm air gap between two vertical glass panes, $k_{T_1}$ =2.97739($W/m^2K$), $Q_İ$=41.08799 (W), and $Q_{rad}$ = 6.82543 (W) were found for Mugla. When the air gap thickness increases to 13.4 mm, $k_{T_1}$ and $Q_İ$ reduced while $Q_{rad}$ increased. According to the optimum air gap for Muğla of 13.4 mm, $k_{T_1}$=1.19423($W/m^2K$), $Q_{opt}$=16.48035 (W), and $Q_{rad}$ = 37.56109 (W) were calculated. For a 28 mm air gap, $k_{T_2}$=1.21752($W/m^2K$), $Q_{Ta}$=16.80186 (W), and $Q_{rad}$ = 37.05953 (W) were calculated.

Table 2. Effect of different air gap thickness on insulation in Mugla.

| Air Gap mm | Total Heat Transfer Coefficient $W/m^2K$ | Heat Transfer W | Radiation Heat Transfer W |
|---|---|---|---|
| 1 | 2.97739 | 41.08799 | 6.825430 |
| 2 | 2.65739 | 36.67211 | 12.29340 |
| 3 | 2.39951 | 33.11329 | 16.61407 |
| 4 | 2.18725 | 30.18410 | 20.24318 |
| 5 | 2.00949 | 27.73103 | 23.29653 |
| 6 | 1.85845 | 25.64670 | 25.64671 |
| 7 | 1.72854 | 23.85380 | 28.14906 |
| 8 | 1.61559 | 22.29520 | 30.10897 |
| 9 | 1.51651 | 20.92778 | 31.83287 |
| 10 | 1.42887 | 19.71840 | 33.36098 |
| 11 | 1.35081 | 18.64126 | 34.72484 |
| 12 | 1.28083 | 17.67553 | 35.85720 |
| **13.4** | **1.18895** | **16.40751** | **37.56106** |
| 14 | 1.19330 | 16.44308 | 37.53140 |
| 16 | 1.19580 | 16.50202 | 37.44084 |
| 18 | 1.20035 | 16.54493 | 37.36083 |
| 20 | 1.20444 | 16.62129 | 37.28914 |
| 22 | 1.20814 | 16.67235 | 37.22421 |
| 24 | 1.21152 | 16.71903 | 37.16485 |
| 26 | 1.21463 | 16.76202 | 37.11019 |
| 28 | 1.21753 | 16.80186 | 37.05953 |

Table 3. $x_{opt}$ and $Q_{opt}$ according to the provinces

| Cities | $x_{opt}$ mm | $Q_{opt}$ W | $Q_{rad}$ W |
|---|---|---|---|
| Manisa | 13.4 | 16.40 | 58.74 |
| İzmir | 14 | 13.95 | 33.65 |
| Kütahya | 12.2 | 24.06 | 48.04 |
| Uşak | 12.5 | 21.47 | 44.75 |
| Afyon | 12.2 | 24.06 | 48.04 |
| Aydın | 13.4 | 16.40 | 58.74 |
| Denizli | 13 | 18.92 | 41.25 |
| Muğla | 13.4 | 16.40 | 58.74 |

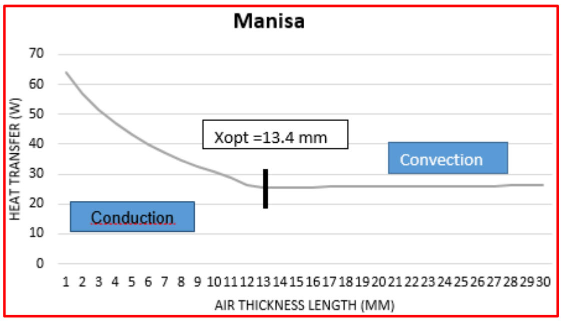


Figure 2. Optimum air gap thickness for Manisa.

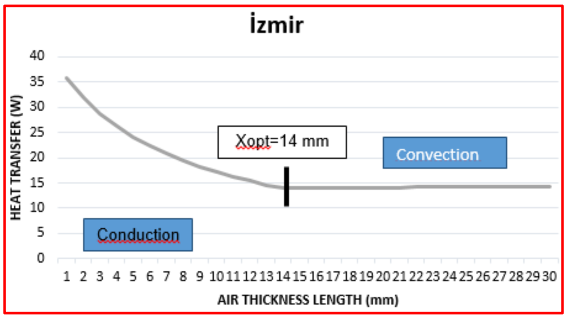


Figure 3. Optimum air gap thickness for İzmir.

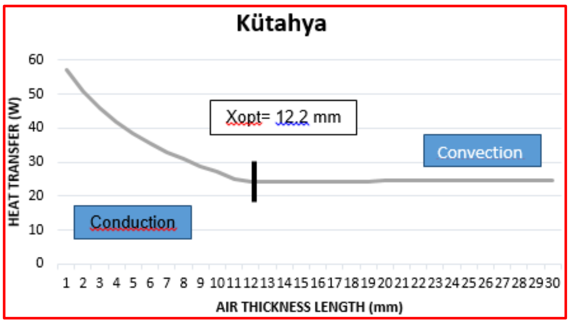


Figure 4. Optimum air gap thickness for Kütahya.

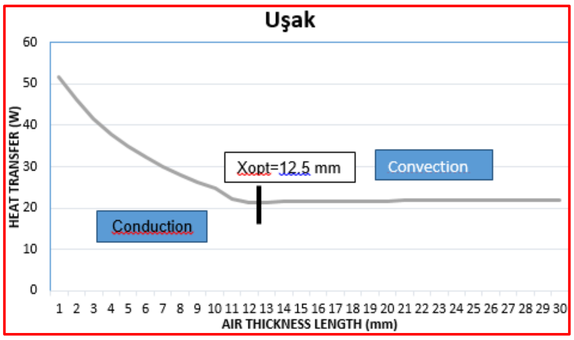


Figure 5. Optimum air gap thickness for Uşak.

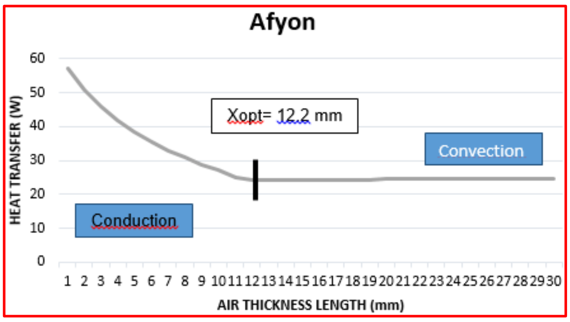


Figure 6. Optimum air gap thickness for Afyon.

Due to conduction properties behaving as solid material in an air gap up to 13.4 mm, $k_T$ and $Q_i$ reduce while $Q_{rad}$ increases. When the air gap is increased above 13.4 mm, the conduction property of air transforms to convection. In this situation, above the optimum air gap, $k_{T_2}$ and $Q_{Ta}$ are increased showing a negative effect.

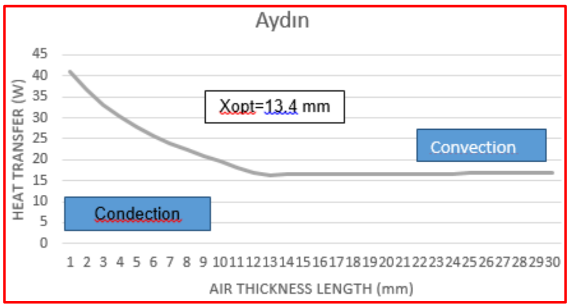


Figure 7. Optimum air gap thickness for Aydın.

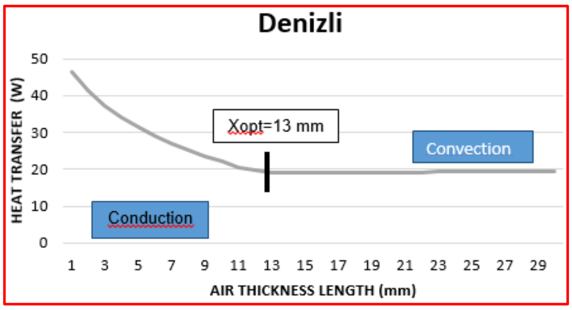


Figure 8. Optimum air gap thickness for Denizli.

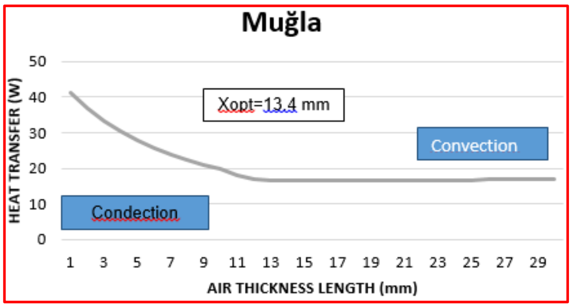


Figure 9. Optimum air gap thickness for Muğla.

## 4 Conclusion

This study researched the effect of an air gap from 1 mm to 280 mm thick between two vertical glass panes in windows in eight cities in the Aegean region. According to the results of the study, as the air gap increases to the optimum air gap, there is a positive effect on heat transfer by convection, while above the optimum air gap there is a negative effect. With optimum calculated as 13.4 mm for Mugla, when the air gap is increased to 280 mm $k_{T_2}$ and $Q_{Ta}$ increase. In cities with the same exterior air temperature, $x_{opt}$ does not change as the air properties are the same. As heat loss from outer walls is greatest from windows, developing insulation techniques to reduce heat loss from windows and determining the optimum air gap thickness for each city separately is of importance in terms of heat losses and costs.

## 5 Acknowledgment

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## Nomenclature

$Ra$ : Rayleigh Number (Dimensionless)
$Pr$ : Prandtl Number (Dimensionless)
$g$ : Gravitational Acceleration $(m^2/s)$
$\beta$ : Expansion Coefficient $(1/°K)$
$T_1$ : Temperature of Interior Environment (°C)
$T_2$ : Temperature of Exterior Environment (°C)
$L_h$ : Air Gap Length (m)
$\vartheta$ : Kinematic Viscosity of Air $(m^2/s)$
$k_T$ : Total Heat Transfer Coefficient $(W/m^2.K)$
$h_i$ : Heat Transfer Coefficient for Interior Convection $(W/m^2.K)$
$h_d$ : Heat Transfer Coefficient for Exterior Convection $(W/m^2.K)$
$h_h$ : Heat Transfer Coefficient for Air Gap Convection $(W/m^2.K)$
$k_g$ : Heat Transfer Coefficient for Glass $(W/m^2.K)$
$l_g$ : Glass Thickness (m)
$H$ : Window Height (m)
$Q_i$ : Heat Conduction below Optimum Air Gap (W)
$Q_{opt}$ : Heat Transfer within Optimum Air Gap (W)
$Q_{Ta}$ : Heat Convection above Optimum Air Gap (W)
$Q_{rad}$ : Heat Transfer Amount by Radiation (W)
$Q_{T_1}$ : Total Heat Transfer Amount below Optimum Air Gap (W)
$Q_{T_2}$ : Total Heat Transfer Amount above Optimum Air Gap (W)
$\sigma$ : Stefan- Boltzmann Constant $(W/m^2.K^4)$
$\varepsilon_1$ : Diffusivity of First Pane (Dimensionless)
$\varepsilon_2$ : Diffusivity of Second Pane (Dimensionless)
$\varepsilon$ : Diffusivity of Two Facing Panes (Dimensionless)
$x_{opt}$ : Optimum Air Gap (mm)
$k_{T_1}$ : Total Heat Transfer Coefficient Calculated below Optimum Air Gap $(W/m^2.K)$
$k_{T_2}$ : Total Heat Transfer Coefficient Calculated above Optimum Air Gap $(W/m^2.K)$

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