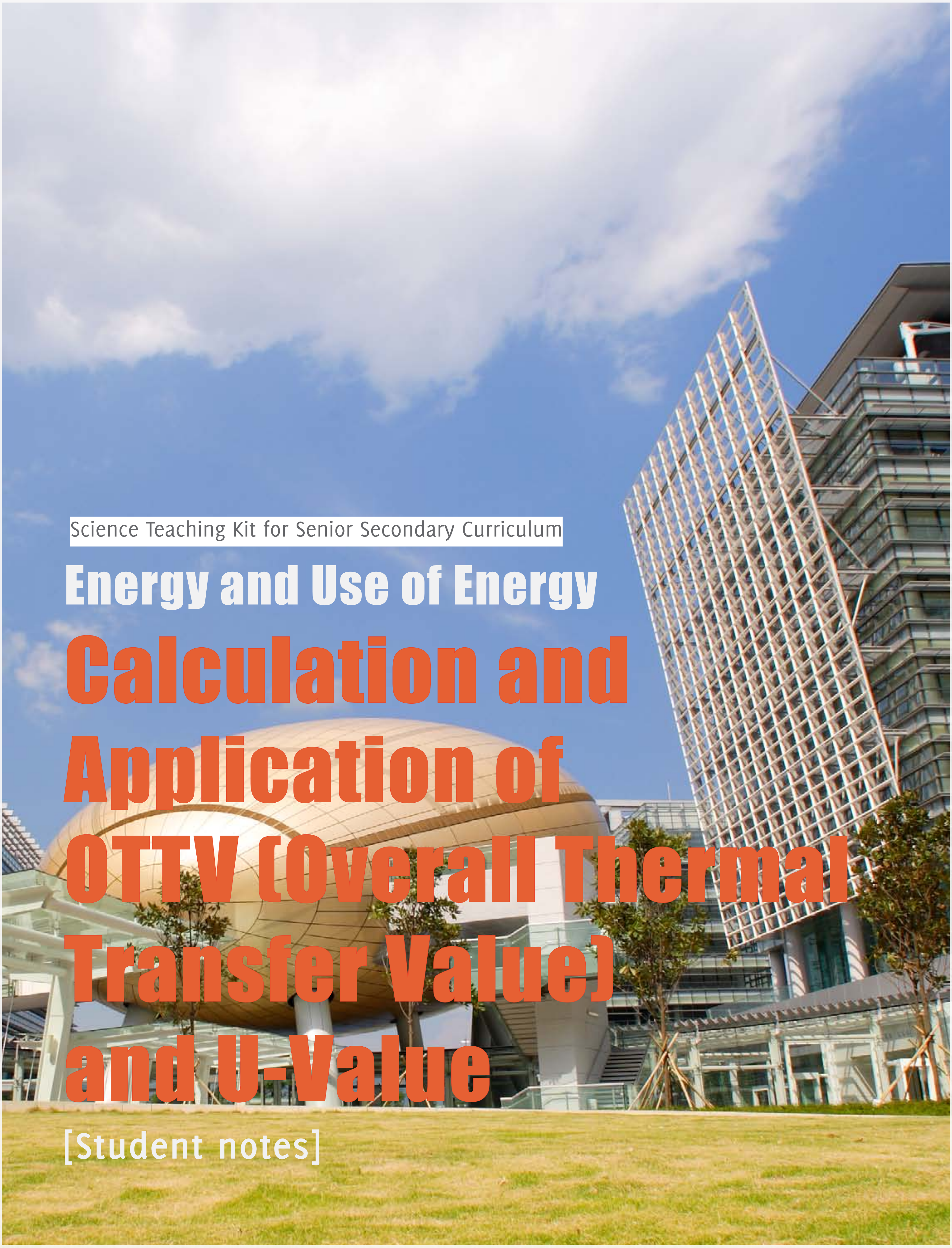

Science Teaching Kit for Senior Secondary Curriculum

Energy and Use of Energy

Calculation and Application of OTTV (Overall Thermal Transfer Value) and U-Value

[Student notes]

Organizer

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Contents

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Topic 06
Calculation and Application of OTTV and U-value

Major teaching areas

Physics: Chapter VIII Energy and Use of Energy

- Energy Efficiency in Building and Transportation

Interdisciplinary teaching areas

Design and Applied Technology

- Strand 3 Value and Impact

Liberal Studies

- Module 2 Hong Kong Today
- Module 6 Energy Technology and Environment

Learning objectives

- To understand the meaning of U-value
- To calculate the OTTV
- To apply basic OTTV calculations in problem solving
- To evaluate the thermal performance of different building designs via scientific measurements

Learning plan

Lesson	Contents
Lesson 1 Calculation and Application of OTTV and U-value	• 1.1.1 The principles of U-value • 1.1.2 The U-values of common construction materials • 1.2.1 The principles of OTTV • 1.2.2 The OTTV equation in Hong Kong • 1.3.1 Discussion on the relationship between building designs and OTTV value • 1.3.2 Discussion on the relationship between types of glass and OTTV value • 1.4 OTTV requirements in Hong Kong • Exercise 1 Calculation of OTTV for a building under Hong Kong OTTV requirements • Exercise 2 Discussion on the limitations of OTTV in regulating the energy efficiency of a building

Lesson 1
Calculation and Application of OTTV and U-value

1.1 What is U-value?

1.1.1 Principles of U-value

U-value is a measure of **the rate of heat transfer** through a **one-square-metre area** of a material for **every temperature degree difference** under ***a standardized condition**.

$$U = \frac{Q}{A \cdot TD_{eq}}$$

**The usual standard is a temperature gradient of 24 °C, at 50% humidity with no wind.*

U-value with SI units of $Wm^{-2}K^{-1}$

where Q stands for rate of heat transfer in Watt W;
A stands for the area of the material calculated in square metres m^2;
TD_{eq} stands for the equivalent temperature difference in Kelvin scale K.

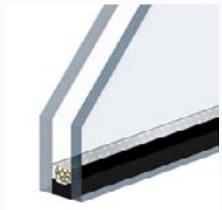
1.1.2 U-values of Common Construction Materials


Reinforced concrete


Brick

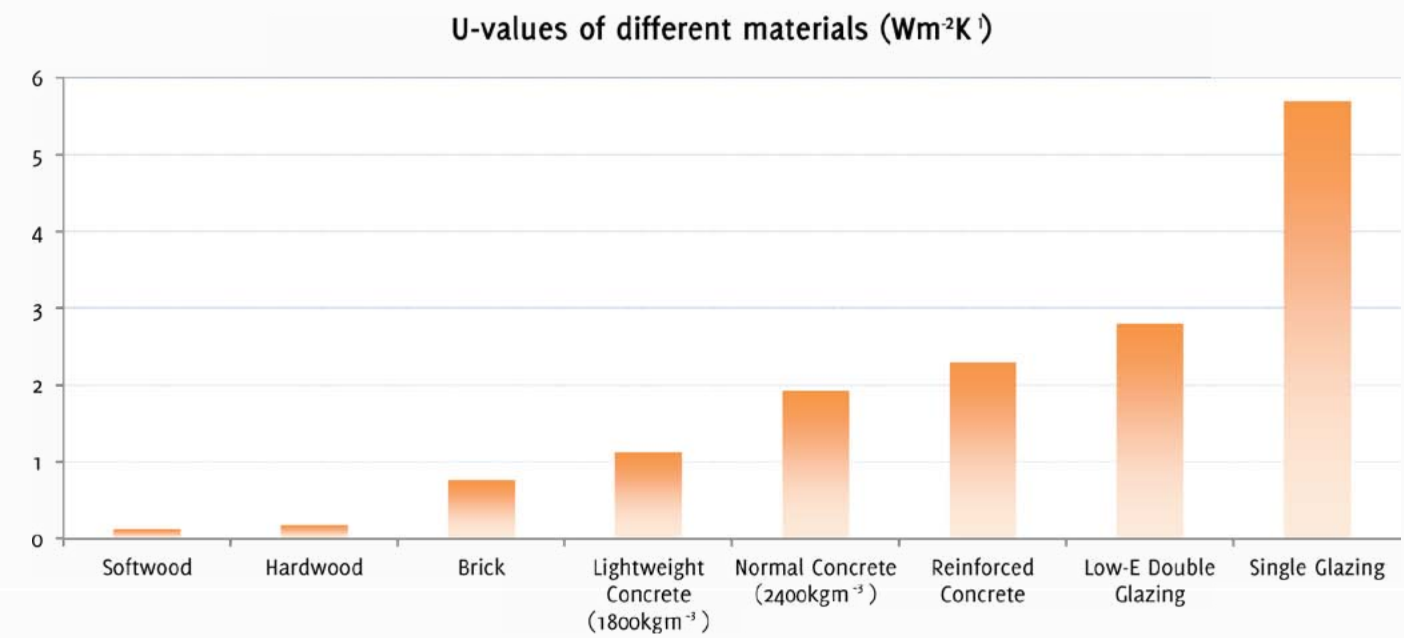

Hardwood

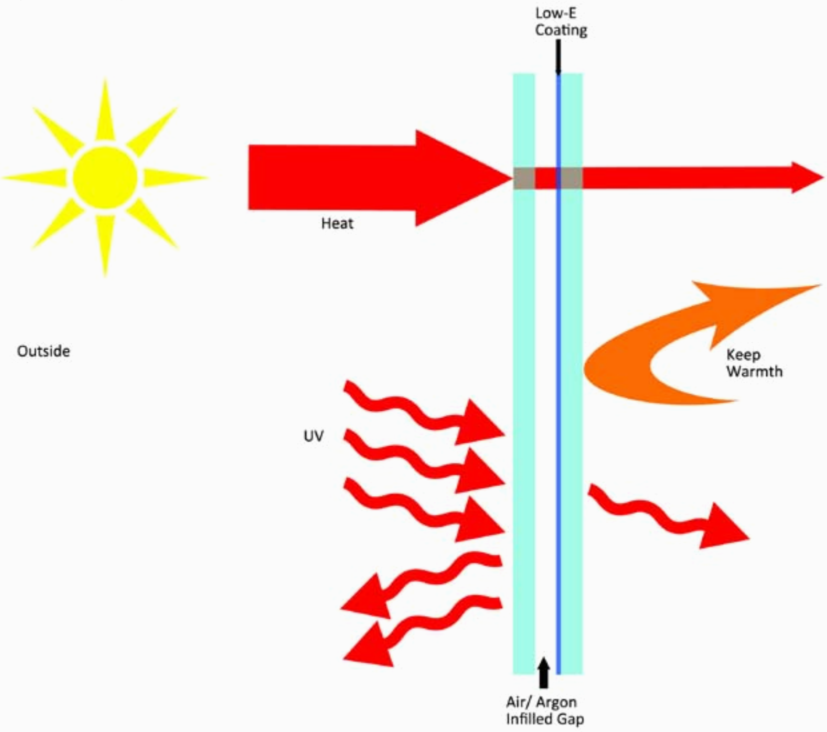

Softwood


Double glazing

Material	U-value ($Wm^{-2}K^{-1}$)	Material	U-value ($Wm^{-2}K^{-1}$)
Softwood	0.13	Normal Concrete (2400 kgm^{-3})	1.93
Hardwood	0.18	Reinforced Concrete	2.3
Brick	0.77	Low-E Double Glazing	2.8
Light Weight Concrete (1800 kgm^{-3})	1.13	Single Glazing	5.7

source: www.puravent.co.uk





Low-E glass (E = thermal emissivity) is a construction material that is coming into wide use. How does low-E glass minimize the heat gain inside the building?

▲ The Veterinary Laboratory at Tai Lung, Sheung Shui uses low-E glass on its external façade to reduce solar heat gain.
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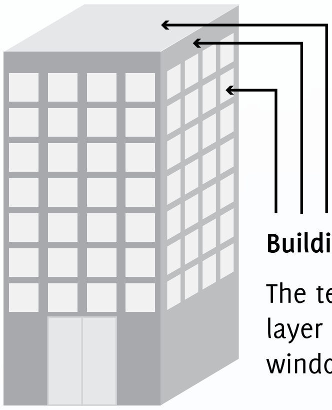
1.2 What is OTTV?

OTTV stands for 'Overall Thermal Transfer Value'. It is a value that indicates the average rate of heat transfer into a building through the building envelope.

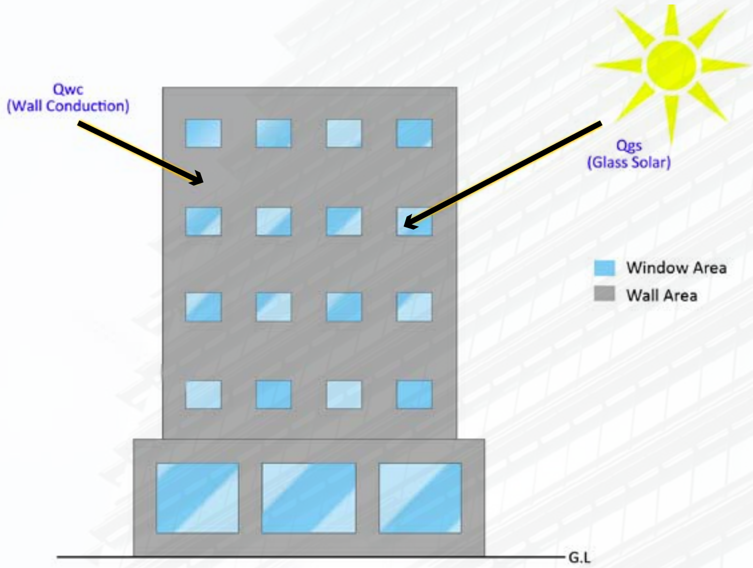


Building envelope

The term building envelope refers to the outermost layer of a building. It includes the roof, the walls and windows of all sides.

Its two major components include:

1. Rate of heat transfer through conduction through opaque walls, Q_{wc}
2. Rate of heat transfer through solar radiation through window glass, Q_{gs}



1.2.1 Principles of OTTV

The rate of heat transfer through a building envelope can be expressed as:

$$OTTV = \frac{\Sigma Q}{\Sigma A}$$

where Q = total rate of heat transfer through envelope (W)
A = gross area of building envelope (m^2)

$$= \frac{Q_{wc} + Q_{gs}}{A_w + A_f}$$

1 Peking Road uses a triple-glazed active wall system, combining three layers of low-E clear glass with a ventilated cavity that results in high light transmission and a low OTTV.

1.2.2 The OTTV Equation in Hong Kong:

$$Q_{wc} = A_w \cdot U_w \cdot \alpha \cdot TD_{eq}$$

$$Q_{gs} = A_f \cdot SC \cdot ESM \cdot SF$$

where A_w, A_f = wall and window area (m^2)
U_w = U-values of wall ($Wm^{-2}K^{-1}$)
α = solar absorptivity of wall
TD_{eq} = equivalent Temperature Difference (K)
SC = Shading Coefficient of the glazing
ESM = External Shading Multiplier
SF = Solar Factor (Wm^{-2})

Solar absorptivity of wall α

$$Q_{wc} = A_w \cdot U_w \cdot \alpha \cdot TD_{eq}$$

Solar absorptivity α is a multiplication constant to the equivalent temperature difference depending on the exterior surface and colour. For example, the solar absorptivity of black concrete is 0.91 while that of brown concrete is 0.85. The heat transfer is higher for concrete of darker colour.

Equivalent Temperature Difference TD_{eq}

$$Q_{wc} = A_w \cdot U_w \cdot \alpha \cdot TD_{eq}$$

In the following calculation, we simplify the equivalent temperature difference into measured temperature difference between indoors and outdoors.

Shading Coefficient of the glazing SC

$$Q_{gs} = A_f \cdot SC \cdot ESM \cdot SF$$

The shading coefficient is the ratio of the solar heat gain through a particular type of glass under a specific set of conditions to the solar heat gain through that of double strength sheet clear glass under the same conditions. The higher the shading coefficient is, the lower the shading performance of the glass.

External Shading Multiplier ESM

$$Q_{gs} = A_f \cdot SC \cdot ESM \cdot SF$$

The external shading multiplier is the shading coefficient to be multiplied with the shading coefficient of the glazing SC. The projections over the windows, or at the sides of the window, or a combination of both, provide shading effects on the fenestration and can significantly reduce the heat transfer through the glazing.

Solar Factor SF

$$Q_{gs} = A_f \cdot SC \cdot ESM \cdot SF$$

The solar factor is the hourly radiation per unit area for horizontal and vertical surfaces. Energy simulation has calculated solar factors for the Hong Kong climate at various orientations.

The OTTV equation for external walls in Hong Kong:

$$OTTV = \frac{\Sigma Q}{\Sigma A}$$

$$= \frac{Q_{wc} + Q_{gs}}{A_w + A_f}$$

$$= \frac{(A_w \cdot U_w \cdot \alpha \cdot TD_{eq}) + (A_f \cdot SC \cdot ESM \cdot SF)}{A_w + A_f}$$

Additional calculation of OTTV for roofs

As the OTTV for roofs is similar to that for walls, and the value for skylights is similar to that of windows, the roof can be taken as part of the walls in calculating OTTV while skylight glazing can be treated as part of the windows in the calculation.

However, when external shading is considered as a shading projection over windows, the heat transfer of the projections over windows should not be included in the OTTV of the roof. According to the Building (Planning) Regulations (Cap. 123 F), an external shading should not project more than 1.5 m from the external wall.

The external shading of IFC 2 is not considered part of the roof in OTTV calculation.

1.3 Building Design and OTTV

The OTTV of a building is affected by the following factors:

- Building orientation (Temperature Difference)
- Material of walls and roof (U-value)
- External finish and colour of walls (Solar Absorptivity)
- Type of glass (Shading Coefficient)
- Shading of windows (External Shading Multiplier)

1.3.1 Comparing Different Wall Designs

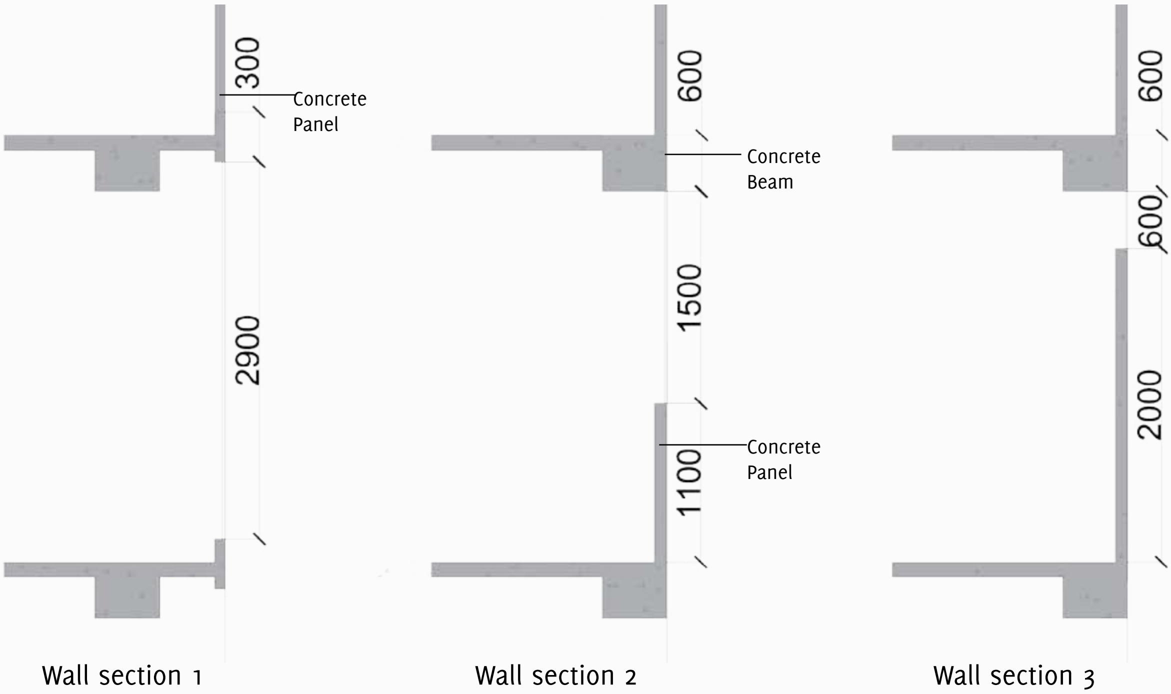


Fig. 1 3 wall sections with different fenestration sizes

Study the above wall sections and the following information:

a. All three walls are south-facing
b. Assume the width of the walls is 1 m
c. All three windows use tinted glass with a shading coefficient (SC) of 0.7
d. Solar Factor = 191 Wm^{-2}
e. External Shading Multiplier (ESM) = 1
f. All walls and concrete beams have the same external surface and colour
g. Solar absorptivity of all walls and beams = 0.58
h. Equivalent Temperature Difference (K) =1.4 K

i. Given that the U-value of a 600 mm concrete beam = 1.51 $Wm^{-2}K^{-1}$
the U-value of a 100 mm concrete panel = 2.32 $Wm^{-2}K^{-1}$

Calculation of OTTV of the three walls:

Note: The Wall Conduction of Concrete Beams and Concrete Panels are different - therefore they must be calculated separately because of the different U-values.

OTTV of Wall section 1 $= \dfrac{Q_{wc} + Q_{gs}}{\Sigma A} = \dfrac{(A_w \cdot U_w \cdot \alpha \cdot TD_{eq}) + (A_f \cdot SC \cdot ESM \cdot SF)}{A_w + A_f}$

OTTV of Wall section 2 $=$

OTTV of Wall section 3 $=$

[Discussion]

1. Based on the drawings and the OTTV calculations, what conclusion can you draw regarding the OTTV value in relation to the areas of the wall and the window?

1.3.2 Comparing Different Types of Glass

Referring to Fig. 1, in wall section 2, if the tinted glass ($SC = 0.7$) is substituted by reflective glass ($SC = 0.4$), and other conditions remain the same, how would the result change?

OTTV of Wall section 2 $=$

[Discussion]

1. Compare the result in case 1 and explain the difference.

1.4 OTTV Requirements in Hong Kong

The Building (Energy Efficiency) Regulation 'B(EE)R' came into effect in 1995. The following buildings are covered under the B(EE)R:

1. Commercial buildings, except for domestic, industrial, bulk storage, and utility buildings such as sub-stations and power stations
2. Hotels defined by the Hotel and Guesthouse Accommodation Ordinance

The B(EE)R aims at reducing heat transfer through the building envelope thus minimizing electricity consumption for air-conditioning by requiring the external walls and roofs of commercial buildings to be designed and constructed for a suitable OTTV. The suitable level of OTTV and the methodology of OTTV calculations are specified in the Code of Practice for Overall Thermal Transfer Value in Buildings 1995 (the OTTV Code).

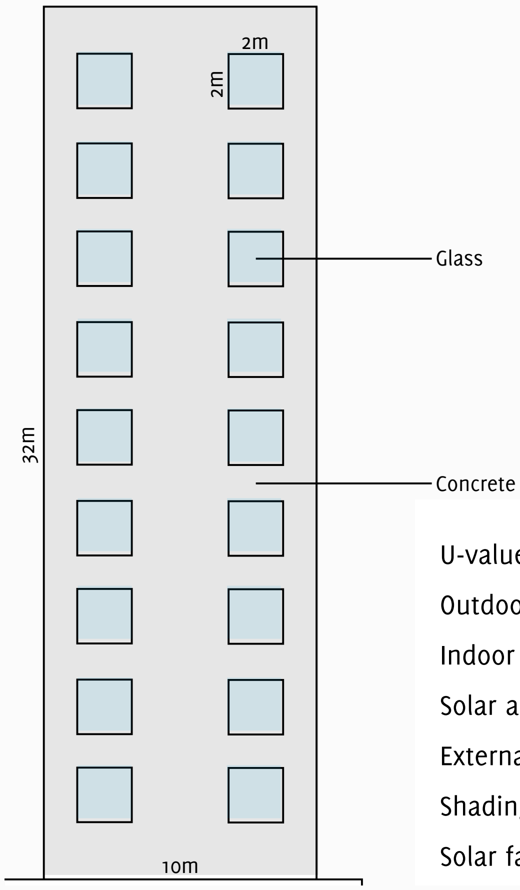
During the second review of the OTTV requirements by the Buildings Department, the OTTV Code was subsequently revised as below:

- In the case of a building tower, the OTTV should not exceed 24 Wm^{-2}
- In the case of a podium, the OTTV should not exceed 56 Wm^{-2}
- Open-front shops or the like on ground level may be exempted from the OTTV calculations upon application

Source: Building (Energy Efficiency) Regulation, Hong Kong Government, 1995.

[Exercise 1]

1. Study the drawing and figures below and calculate the OTTV of the building.
Assume that the four elevations of the building are identical. Calculate the OTTV of the building. Determine if this building follows the OTTV Code in Hong Kong (24 Wm^{-2}).



U-value of a wall $U_w = 1.9\ Wm^{-2}K^{-1}$

Outdoor temperature = 28.4 °C

Indoor temperature = 27 °C

Solar absorptivity of wall α = 0.58

External shading multiplier ESM= 1

Shading coefficient of window glass SC= 0.4

Solar factor SF = 191 Wm^{-2}

$$OTTV = \frac{Q_{wc} + Q_{gs}}{\Sigma A}$$

$$= \frac{(A_w \cdot U_w \cdot \alpha \cdot TD_{eq}) + (A_f \cdot SC \cdot ESM \cdot SF)}{A_w + A_f}$$

[Exercise 2]

Please study the article and information below:

Limitations of the OTTV Standard in Hong Kong

The biggest limitation of the OTTV method is that it only deals with the building envelope and does not consider other aspects of building design (such as lighting and air-conditioning) and the coordination of building systems to optimize the combined performance. The use of OTTV as the only control parameter is inadequate and cannot ensure energy is used efficiently in the building. Before other energy codes are implemented, the effect of the OTTV standard on 'real' energy savings is questionable, although it helps to increase concern and awareness of energy efficiency matters.

The OTTV method has also been criticized for limiting design freedom in architecture and restricting innovation. Although the OTTV approach has made code compliance simple for conventional building designs, it has tended to restrict designers from innovation and more challenging work. If alternative paths for code compliance are not provided, innovative designs that may exceed the OTTV limits but can achieve a higher overall efficiency will be excluded and discouraged. For example, designs employing daylight to reduce energy consumption by electric lights will be restricted.

Evolution of the ASHRAE's energy standards has indicated that more flexible approaches are needed to encourage innovative energy efficient design in buildings. Many countries are now moving towards energy performance criterias which give designers greater flexibility. To maintain its economic competitiveness in the international market, Hong Kong should not lag behind the current development.

Other problematic areas are related to the implementation issues. At present, the Code of Practice for OTTV only provides a manual approach to the OTTV calculations. The compliance and calculation procedure is often lengthy and time-consuming, so that checking of the results during submission and enforcement is not easy. The lack of a competent professional engineer to be responsible for the OTTV submission is also affecting the actual implementation. In addition, as there are no control measures for the design and operation of existing buildings, which constitute a large portion of the energy consumption, the energy savings arisen from the OTTV standard are limited.

— Extract from *Overall Thermal Transfer Value (OTTV): How to Improve Its Control in Hong Kong* by Hui, Sam C. M.,1997

Revision of the OTTV Code

The OTTV Code has been revised throughout the years as below:

a) In the case of a tower, the OTTV	should not exceed 35 Wm^{-2} (first implemented in 1995) should not exceed 30 Wm^{-2} (first revision) should not exceed 24 Wm^{-2} (second revision)
b) in the case of a podium, the OTTV	should not exceed 80 Wm^{-2} (first implemented in 1995) should not exceed 70 Wm^{-2} (first revision) should not exceed 56 Wm^{-2} (second revision)

[Discussion]

1. What are the limitations of the OTTV standard?

2 What are the difficulties of implementing OTTV requirements in Hong Kong?

3 How can the Government improve the standard of OTTV requirements on buildings?

Summary

1. U-value is the rate of heat transfer of a material.
2. The lower the U-value, the higher the resistance of heat flow through the material.
3. OTTV stands for 'Overall Thermal Transfer Value'.
4. The lower the OTTV, the higher the resistance of heat flow through the building envelope.
5. The size of the windows and the type of glass used are important factors for OTTV.
6. OTTV has limitations in addressing the energy efficiency of a building.
7. A combined testing and tailored building energy standard can improve the reliability of OTTV.

Key words

OTTV (Overall Thermal Transfer Value)
U-value
Heat transfer

Further reading

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