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Study of Residential Thermal Transfer Values (RTTV) and Vertical Daylight Factor (VDF) for Hong Kong

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Abstract. In Hong Kong, over one-quarter of the total electricity use was consumed by residential buildings. Recently, the Hong Kong Government issued a practice note namely Design and Construction Requirements for Energy Efficiency of Residential Buildings. This practice note set out the Residential Thermal Transfer Values (RTTV) of building envelopes. To enhance energy efficiency of residential buildings, the RTTV of wall (RTTV_{wall}) and roof (RTTV_{roof}) should not exceed 14 and 4 W/m², respectively. Being one of the most densely populated cities in the world, most of building developments in Hong Kong are high-rise blocks located in densely built zones. The shading effects due to surrounding buildings could substantially restrict the diffuse light coming from the sky. In 2003, a practice note on lighting and ventilation requirements was issued. Referring to the performance-based approach, the note adopted the vertical daylight factor (VDF) to specify the daylighting performance of the building. The VDF should not be less than 8% for habitable rooms and 4% for domestic kitchens. This paper presents the energy performance of recently designed building fulfills the RTTV requirements. It found that VDF is a good indicator to shows the lighting electricity consumption in buildings. For most of the bedroom, about 40% of air conditioning and 3 % lighting energy can be saved.

Keywords: RTTV, VDF, building façade designs

1. Introduction

Currently, buildings in Hong Kong accounted for more than 90% of the total electricity expenditure and over one-quarter of the total electricity use was consumed by residential buildings [1]. In most cities, electricity is mainly used to create thermally and visually comfortable built environments. Air-conditioning and electric lighting represent for the majority of the overall building energy use. In subtropical regions, residential building envelope's cooling load can contribute over one-third to two-thirds of the cooling requirement [2]. The principal objectives of fenestration designs is to limit the heat gain into the buildings. To control the heat transfer from outdoor to interior through the facades of a building, the Hong Kong Government recently issued a practice note namely Design and Construction Requirements for Energy Efficiency of Residential Buildings [3]. This practice note set out the Residential Thermal Transfer Values (RTTV) of building envelopes. To enhance energy efficiency of residential buildings, the RTTV of wall (RTTV_{wall}) and roof (RTTV_{roof}) should not exceed 14 and 4 W/m², respectively. Being one of the most densely populated cities in the world, most of building developments in Hong Kong are high-rise blocks located in densely built zones. The shading effects due to surrounding buildings could substantially restrict the diffuse light coming from the sky particularly for rooms at the lower floors [4]. In 2003, a practice note on lighting and ventilation requirements was issued [5]. Referring to the performance-based approach, the note adopted the vertical daylight factor (VDF) to specify the daylighting performance of the building. The VDF should not be less than 8% for habitable rooms and 4% for domestic kitchens. A high VDF would often mean a large RTTV and vice versa. It seems that there may be a contradiction on building façade designs for achieving the required RTTV and VDF. This paper studies the RTTV and VDF



for typical domestic buildings in Hong Kong. The general correlation between RTTV and VDF was determined. Main features of the findings and building façade design implications are discussed.

2. Residential thermal transfer values and vertical daylight factor

2.1. Residential thermal transfer values (RTTV)

Residential buildings account for 27.7 % of total electricity in Hong Kong [6]. As standard of living increases during previous two decades, most of the residential buildings are installed with air-conditioning units. There are strong demands on governing the thermal performance in residential buildings. In 2014, the RTTV was adopted [3]. Basically, building with a lower RTTV uses less energy for space cooling. On the contrary, the higher the RTTV, more energy is used by air-conditioning system.

In most of the residential buildings, equipment is not operated continuously. During mid-season and non-peak operation, natural ventilation is sufficient for maintaining acceptable indoor environment. It is assumed that Air conditioners operate between April and October [3,7]. New residential buildings usually equipped with heat pump to provide both heating and cooling. In subtropical Hong Kong, heating is only required for not more than one month and hence there is no specific considerations for heating season in the RTTV.

2.2. Vertical daylight factor (VDF)

Hong Kong is one of the highest density cities in the world. Vast of high-rise buildings built closely together. Flats located on lower floors may not be able to admit sufficient daylight when facing heavy obstructions. In 2003, Buildings Department established a performance-based approach as an alternative path for buildings cannot fulfil the requirement stated in Building (Planning) Regulations [8] to obtain approval. This approach set minimum requirements of VDF for habitation rooms and kitchens. VDF is the amount of daylight fell on a vertical window compared to the illuminance level of an unobstructed CIE overcast sky. Under the same glazing type and internal layout, rooms with higher VDF have higher indoor illuminance levels.

3. Computer simulation approach

Computer-based building energy simulation has proved useful in assessing different daylighting schemes [10]. In this study, EnergyPlus was used to model the daylighting and energy performances of a residential building. It is capable to analyse a wide range of daylight design features and is able to calculate internally reflected component inside the thermal zones and specular & diffuse reflections from adjunct surfaces.

3.1. Building descriptions

A 31-floor residential tower which was designed and built recently was selected for this study. Windows are facing three major orientations includes southeast, southwest and northwest. The designers prevented to locate window on northeast direction as there is another high-rise hotel tower in this direction within 5m from the site boundary. On southwest direction, there are some old buildings which are relatively low compared to the building being studied. On southwest, there are few tall buildings mixed with some shorter one. They affect the daylight level at lowest floors. For the northwest direction, the obstruction is taller than other directions. Buildings in Hong Kong need to comply with the Building Energy Code (BEC) [10]. The government promote green buildings by granting an additional 10% gross floor area concessions for building completed green building assessment [11]. BEAM Plus [7] is the most commonly used green building assessment tool in Hong Kong. So, most of the new buildings are designed to conform the requirement in BEC and BEAM Plus. Table 1 shows the input parameters and building information while Figure 1 shows the building layout of the residential building.

Table 1. Descriptions of residential building

Building type and storey		31-Storey Residential building above 5-storey commercial podium	
Floor area		Total Area: 14,371 m ² Air-conditioned area: 9,719 m ² (Living and dining room: 4,634m ² Bedroom: 5,085 m ²)	
Envelop	Opaque surface	U-value	Exterior Wall: 3.93 W/m ² K Roof: 0.36 W/m ² K
	Glazing	Shading Coefficient	0.57
		Visual transmittance	0.4
		U-value	5.71 W/m ² K
	Shading is provided to simulate occupant's behaviours		
	Window to wall ratio		0.21
RTTV _{wall}		13.29 W/m ² K	
RTTV _{roof}		0.98W/m ² K	
Internal load	Occupancy	Living and dining room: 2 persons per room Bedroom: 2 persons per room	
	Lighting	Living and dining room: 15 W/room Bedroom: 13 W/room LED dimmable lighting Design illuminance level: 150lx (living and dining room) 100 lx (bedroom) Living and dining room: 6:00 - 8:00; 13:00 - 14:00; 18:00 - 22:00 Bedroom: 5:00 - 9:00; 13:00 - 17:00; 18:00 - 24:00	
		Equipment	
		Living and dining room: 142 W/room Bedroom: 45 W/room	
HVAC	System	Split-type heat pump	
	Coefficient of Performance	2.7 (Heating); 2.6(Cooling)	
	Indoor Temperature	24°C	
	Operation	Living and dining room: 13:00 - 22:00; April - October Bedroom: 0:00 - 7:00; 13:00 - 24:00; April - October	

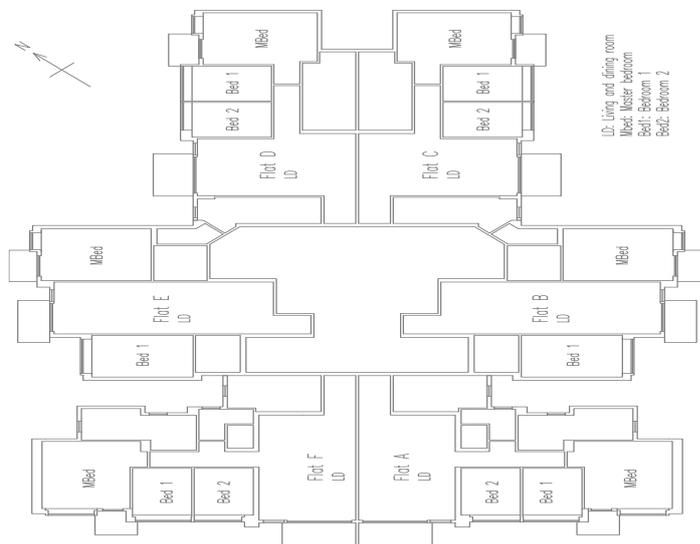


Figure 1. Floor plan for the residential building.

3.2. Weather file

EnergyPlus can conduct hourly and sub-hourly simulation by using 8,760-hour record of measured weather data. Weather varies from a year to another. It is essential to develop a weather database which is typical or representative of a particular geographical area so that different schemes can be readily compared. RTTV [3] adopted the typical meteorological year by Chan et al. [12] for performing complex external shading calculation. This weather data was used in this study.

4. Result

The building comprises of 31 floors. Simulations were conducted for every five floors (i.e. 1st, 6th, 11th, 21st, 26th and 31st). The neighbourhood buildings were also included in the simulation model to simulate the shading effect of these surrounded buildings.

4.1. Visual Performance

To understand the energy saving opportunity offered by daylight-linked control system, total fraction of time that daylight can provide sufficient indoor illuminance is important. Table 2 reports the findings. Except master bedrooms and living and dining room, over 80% of daytime, daylight provides sufficient illuminance level. There are two reasons for bedrooms outperform other rooms. First, balconies provided for living and dining room and master bedroom usually block significantly the daylight entering the into the room. Second, it is found that living and dining room and master bedrooms are more sensitive to the floor level. In master bedroom and living and dining room, the differences between the bottom and the top floor may over 15%. Balconies blocks certain among of light from zenith which is the brightest part of sky under overcast sky condition. So, rooms can only admit small amount of light fluxes horizontally and therefore, more sensitive to external obstruction. For the remaining rooms, the differences between topmost and lowest floor are around 3% only. The VDFs were calculated for all rooms as shown in Table 3. VDF has a good agreement with the fraction of time daylight exceeds the design illuminance level. In the living and dining room of Flat E, both VDF and the fraction of time daylight exceeded the design illuminance level change significantly with floor level. The daylight level has a constant increase from 1/F to 16/F with a becomes steady between 21/F and 31/F.

Table 2. Percentage of time indoor daylight illuminance exceed daylight level during daytime

		1/F	6/F	11/F	16/F	21/F	26/F	31/F
Flat A	Living and Dining room	67.1%	71.0%	74.7%	77.0%	77.5%	77.7%	77.8%
	Master Bedroom	63.3%	64.7%	68.5%	73.3%	73.4%	74.2%	73.7%
	Bedroom 1	81.6%	83.2%	84.1%	84.3%	83.7%	83.8%	83.8%
	Bedroom 2	80.8%	82.8%	83.9%	84.6%	84.0%	84.1%	84.1%
Flat B	Living and Dining room	74.1%	75.2%	76.4%	77.7%	78.8%	78.5%	77.5%
	Master Bedroom	78.7%	80.4%	80.0%	80.7%	80.7%	80.9%	81.0%
	Bedroom	81.1%	81.1%	81.4%	81.8%	82.2%	82.3%	82.3%
Flat C	Living and Dining room	60.2%	70.2%	72.5%	73.2%	73.5%	73.9%	74.2%
	Master Bedroom	77.3%	79.4%	79.9%	80.7%	79.8%	80.0%	80.1%
	Bedroom 1	82.2%	82.8%	83.1%	83.4%	83.1%	83.2%	83.3%
	Bedroom 2	81.0%	81.4%	81.7%	82.0%	82.3%	82.4%	82.5%
Flat D	Living and Dining room	58.4%	62.5%	65.7%	70.1%	70.9%	71.5%	71.8%
	Master Bedroom	73.9%	74.8%	76.3%	80.8%	81.3%	80.9%	80.5%
	Bedroom 1	82.6%	81.9%	84.0%	83.8%	84.2%	83.8%	83.8%
	Bedroom 2	81.4%	82.0%	82.4%	83.1%	83.4%	83.5%	83.6%
Flat E	Living and Dining room	55.7%	61.8%	65.5%	70.1%	73.6%	74.0%	75.3%
	Master Bedroom	79.2%	79.4%	81.3%	82.2%	83.3%	83.5%	83.0%
	Bedroom	77.4%	78.8%	80.8%	82.5%	83.3%	83.4%	83.5%
Flat F	Living and Dining room	66.1%	70.0%	74.2%	77.2%	77.4%	77.6%	77.7%
	Master Bedroom	64.3%	65.1%	69.2%	73.1%	73.1%	73.8%	73.3%
	Bedroom 1	81.9%	83.8%	84.2%	84.3%	83.7%	83.8%	83.8%
	Bedroom 2	81.6%	82.2%	84.0%	84.3%	84.6%	84.6%	84.7%

4.2. Energy

The energy consumptions for lighting and air-conditioner with and without daylighting control are shown in Figure 2. Bedrooms consume more electricity than living and dining rooms as bedroom has a longer operating hours of lighting during daytime. 40% of lighting electricity can be saved for bedroom by daylight-linked control system. Similar to the effect of daylight level, balconies reduce the amount of energy saved and increase the influence by obstruction/floor level.

The energy consumed by air-conditioning was also analysed. Instead of 31/F, 16/F has the highest energy consumption. 31/F is relatively free of obstruction and received more solar radiation. The

fraction of time for windows shaded by internal shading increases. Hence, energy consumed by air-conditioner is slightly decreased for those top floors. With the implement of daylight control, most of the bedrooms can reduce 4% energy used by air conditioners. For living and dining rooms of Flat D has a very low VDF of 13.4% at 1/F. With the implement of daylight control, it helps to reduce the air-conditioning consumption by 6.5% which is the largest among all rooms. There are two plausible explanations. Firstly, this room is severely obstructed and hence, solar radiation is difficult to reach the room, so the total cooling load decreases. Therefore, the air-conditioning energy savings due to the reduction of lighting heat dissipation become significant. Secondly, about half the operation time of air conditioner for living and dining room is during daytime, so the effect of daylight-linked control on the air conditioning energy saving is more significant than that for bedrooms.

Table 3. VDF for each room

		1/F	6/F	11/F	16/F	21/F	26/F	31/F
Flat A	Living and Dining room	24.4	28.0	31.7	34.1	36.0	36.2	36.2
	Master Bedroom	18.7	22.9	26.8	29.2	30.9	31.1	31.1
	Bedroom 1	32.8	37.3	41.5	44.0	45.8	46.0	46.0
	Bedroom 2	33.3	37.6	41.5	43.9	45.8	46.0	46.0
Flat B	Living and Dining room	24.5	30.9	33.4	33.4	33.4	33.4	33.4
	Master Bedroom	25.8	33.3	35.8	35.8	35.8	35.8	35.9
	Bedroom	31.1	37.1	39.2	39.2	39.2	39.2	40.6
Flat C	Living and Dining room	13.6	14.0	14.0	14.0	14.0	14.0	18.4
	Master Bedroom	21.7	28.7	31.0	33.8	33.8	33.8	33.8
	Bedroom 1	25.6	32.0	34.6	35.9	36.0	36.1	38.0
	Bedroom 2	28.7	36.7	39.6	40.7	40.7	40.8	44.6
Flat D	Living and Dining room	13.4	14.2	16.8	21.3	22.8	22.9	25.3
	Master Bedroom	14.5	16.2	19.7	32.0	33.9	34.0	34.0
	Bedroom 1	25.4	27.2	31.8	41.6	43.0	43.2	45.3
	Bedroom 2	25.3	27.7	32.8	39.4	41.5	41.7	44.5
Flat E	Living and Dining room	23.1	24.2	26.7	30.2	33.3	33.6	33.7
	Master Bedroom	24.7	26.1	28.6	31.9	34.6	34.7	34.7
	Bedroom	24.0	26.0	28.6	32.0	34.8	35.0	39.1
Flat F	Living and Dining room	24.3	27.6	31.1	33.8	36.2	36.5	36.5
	Master Bedroom	11.8	14.4	17.1	19.5	21.6	21.9	21.9
	Bedroom 1	34.1	37.6	40.9	43.5	45.7	46.0	46.0
	Bedroom 2	33.6	37.3	40.8	43.4	45.7	46.0	46.0

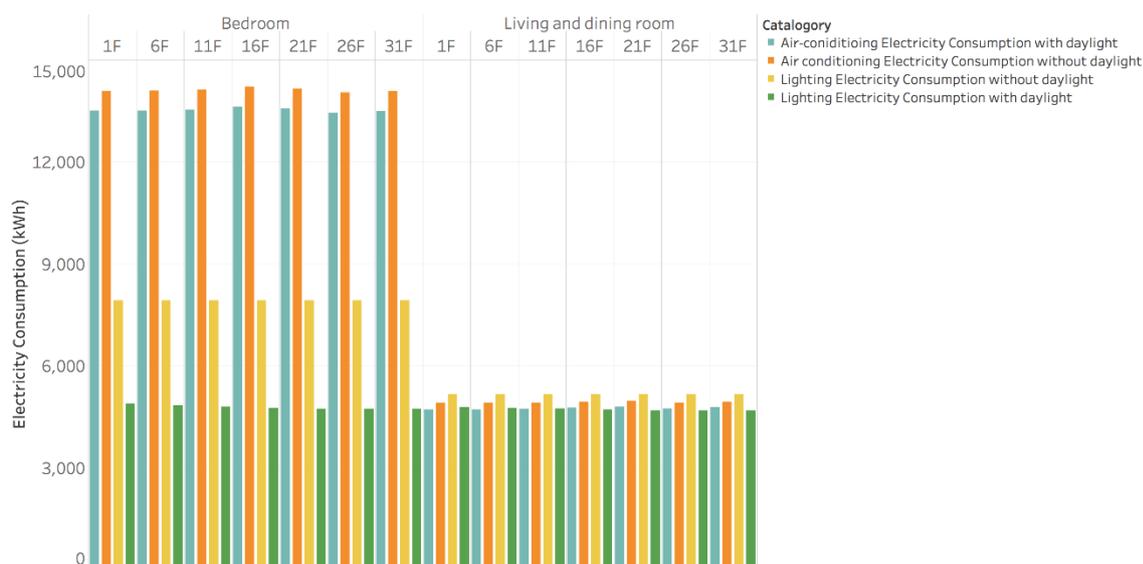


Figure 2. Electricity consumption for different floors of bedrooms and living rooms.

5. Conclusions

In Hong Kong, most of the residential buildings projects in the high-density zone are high-rise multi-storey blocks built closely together. The effects of obstruction on daylighting performance are of interested. Recently the HKSAR Government has introduced a new RTTV to govern the building envelop design. Simulations have been conducted for a newly design residential building which fulfils the daylight and thermal requirement by the government. It is found that VDF is closely related to the indoor illuminance level. Over 80% of daytime, daylight alone can provide sufficient illuminance for most of the bedrooms. For rooms with heavy obstruction, over 50% of daytime, the room is considered sunlit. For most of the bedrooms, 40% of lighting and 3% of air-conditioning energy consumptions can be reduced. It is believed that VDF is closely related to the energy consumptions and visual comfort aspect. This is a snapshot study on VDF and RTTV, more works are required to explore the relationships among VDF, RTTV and visual comfort to assist building designer to optimise their designs in early stage.

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