Cooling Load Analysis of Residential Buildings for Dehumidification/Sub-Cooling Systems in Radiant Cooling

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ABSTRACT

This study aims to propose methods for designing radiant floor cooling system for residential buildings under hot and humid weather conditions, especially the dehumidification/sub cooling equipment to prevent condensation and overcooling by dehumidification operation. For this, cooling load patterns and sensible load ratio (SHR) were analyzed under different physical conditions of residential unit prototypes classified as floor level and directions.
The simulation results provided some directions as to the way of determining the types and capacities of dehumidification/sub-cooling systems. The residential buildings SHR patterns showed that cooling based dehumidifiers with commonly used chilled water are available and does not require any reheat process. For units or rooms that are on the south side, or do not have a balcony, or are on the top floor, the dehumidification/sub-cooling systems would need greater cooling capacities. Otherwise, for the units or rooms with lower sensible load, the dehumidification/sub-cooling systems should be designed focused on dehumidification alone. For example, to have low refrigerant/water temperature, large heat exchange area is needed for active condensing and low air flow rate.

KEYWORDS: Radiant Cooling, Dehumidification, Load Analysis, Residential Building.

1. INTRODUCTION

1.1 Background and objective

As the standards of living of people are higher today, comfort has become an important criteria in residential houses. In connection to this, the demand for a cooling system for residential buildings has increased. Packaged air conditioners (PAC) are widely used in residential houses. However, PACs entail high electric power consumption and the low temperature air supply from PACs cause cold draft and partial discomfort. Therefore, it is necessary to develop more comfortable and energy- efficient cooling systems for residential buildings.

It is often claimed that radiant systems both improve thermal comfort and increase energy efficiency (Watson et al., 2002). In a previous research (Lim et al., 2005), the cooling methods with existing floor heating panel have been presented (Hydronic radiant floor heating system with embedded tubes on the slab has been used for most Korean residential buildings). This research shows that the radiant floor cooling systems in Korea need some dehumidification/sub-cooling systems to prevent condensation. In the above research for the dehumidification/sub-cooling system, existing Packaged Air Conditioners or Fan Coil Units were used. With this equipment, although condensation was prevented well, room air is overcooled before latent heat load is sufficiently eliminated. Therefore, the existing equipment is not the right solutions as a dehumidification system for radiant cooling in residential buildings.

Considering the composed operation mode of radiant panel and dehumidification/sub-cooling systems, the radiant cooling panel was operated alone under light load conditions, and the dehumidification/sub-cooling systems were operated under heavy load conditions. To increase energy efficiencies of radiant floor cooling systems, the capacity of the dehumidification/sub-cooling systems as the cooling load variations of residential buildings such as part load patterns, the amount of room latent load and room SHR should be known.

4. CONCLUSIONS

This study was intended to develop dehumidification methods of radiant floor cooling system. Through a dynamic cooling load analysis, the applicable refrigerant conditions and method of estimating the system capacity were examined.

The simulation results showed that generally used chilled water can be used as the heat exchange medium for dehumidification/sub-cooling system without reheat process in residential buildings considering room SHR and general chilled water coil characteristics.

As for the estimating capacity of the for dehumidification/sub-cooling systems, it can be concluded that the capacity should be estimated under the peak latent load conditions rather than peak total load conditions for general room in residential buildings.

ACKNOWLEDGEMENTS

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The type of dehumidification/sub-cooling system in radiant cooling should be selected considering sensible/latent load ratio of residential units. The sensible/latent load ratio becomes different as the physical conditions (such as floor level, direction and presence of balcony) of residential units.
Therefore, in this study, cooling load patterns of residential buildings in Korea were analyzed in order to propose the method of determining proper capacity of dehumidification/sub-cooling system for radiant floor cooling as load characteristics.

1.2 Methodology

In case of the common rooms in residential buildings in Korea, during 30% of whole cooling period, it was known that operating radiant floor cooling may only cause floor surface condensation (Kim et al., 2001). Ways to prevent surface condensation include preventing infiltration by pressuring ventilation control, mechanical dehumidification and maintaining high surface temperature can be thought. Among these, high surface temperature strategy is not a reasonable method because floor surface should be cooled to cover room cooling load in radiant floor cooling systems. Also, ventilation control strategy is not a way for common residential buildings either, because current residential buildings generally do not have mechanical ventilation systems but natural ventilation through window. Therefore, mechanical dehumidification should be used for preventing condensation.

For real applications, the type, capacity and design conditions of heat exchange medium for the dehumidification system should be determined. In order to determine heat medium conditions and capacity, room latent load ratio should be analyzed. To estimate the required capacity of dehumidification systems, both latent peak load and total peak load should be considered. Therefore, from the simulation results performed for the whole cooling period, sample days for analyzing cooling load were selected by considering room SHR, latent peak load and total peak load and room. For these sample days, load pattern was analyzed and the dehumidification system type and capacity was determined for the simulation model cases.

2. SIMULATION FOR COOLING LOAD ANALYSIS

To conduct simulations for analyzing cooling load of residential buildings, a typical room (living room) in the mid-floor of an apartment building with radiant floor heating system was selected as a model case. In this room, one wall was facing south and the other walls, ceiling, and floor ware in contact with rooms in identical conditions. Simulations ware performed for the summer season according to the standard meteorological data of Seoul (SAREK, 1996).

For analyzing cooling load patterns, the simulation program took into account the transient characteristics of the building structure and has the dynamic control algorithms. From these terms of view, *EnergyPlus,* which is heat balance based simulation program, was used for the simulation. In addition, *EnergyPlus* has more detailed input cases of occupancy schedule and internal load occurrence pattern than other former load analysis tools. The simulation was carried out during the cooling season (May 1st to September 30th). Figure 1 shows the information about the simulation model geometry and thermal zone for analysis modeled with *EnergyPlus*.

The occupancy schedule, lighting schedule and plug load (electrical and electronic appliances) were applied to the simulation more close to real life cycle and situations (Leigh et al., 2005). For internal heat gain values, seated people with light work and fluorescent lighting were applied (ASHRAE, 2005). The input data for the simulation are summarized as shown in Table 1, Figure 2 and Figure 3.

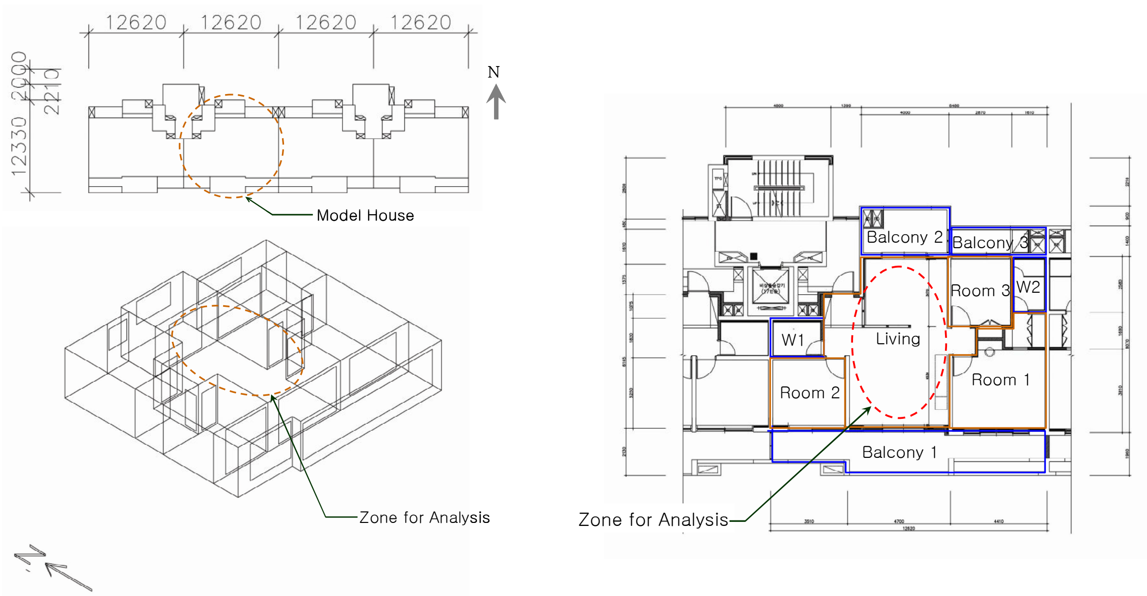

Figure 1. Geometry and plan of the simulation model

Table 1. Summary of Input Data for Simulations for Cooling Load Analysis

Category			Input Data	Remarks
Model House	Apartment Location		37.57°N , 126.97 °E	Seoul
			Middle house , Middle floor	
	Orientation		South	Living room
	Target Room		Area : 40.7㎡ Height(slab to slab) : 2.8m	
Weather Data			Standard weather data for Seoul	
Internal Loads	People	Sensible Heat (Convective)	28.0 W/person	Convection : 0.40 Radiation : 0.60
		Sensible Heat (Radiative)	42.0 W/person	
		Latent Heat	45.0 W/person	
		Number of Occupants	4 persons	
		Activity	Seated, Very light writing	
	Light	Sensible Heat (Convective)	11.8 W/㎡	Convection : 0.59 Radiation : 0.41
		Sensible Heat (Radiative)	8.2 W/㎡	
	Equipment	Sensible Heat (Convective)	8.3 W/㎡	Convection : 0.50 Radiation : 0.50
		Sensible Heat (Radiative)	8.3 W/㎡	
Infiltration Rate			0.6 ACH (constant)	
Operation Conditions	Control Method		Continuous Cooling	Compact HVAC in EnergyPlus
	Set point		26℃ (50% RH)	Design Standards for Energy Conservation for Buildings

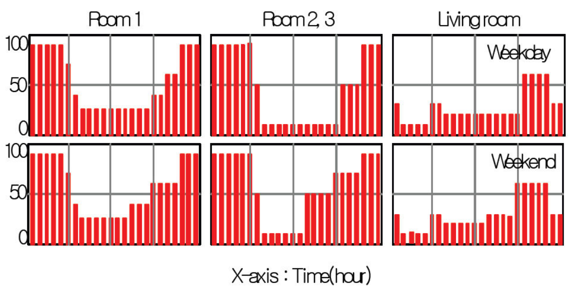

Figure 2. Occupancy schedule

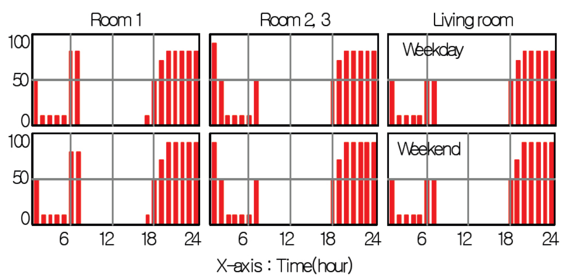

Figure 3. Light & equipment schedule

3. RESULTS AND ANALYSIS

3.1 Sample days for analysis

Dehumidification methods can be classified as cooling-based dehumidification, desiccant dehumidification (using active desiccant wheel) and water absorption dehumidification (using chemical materials with high water absorption characteristic). A former research showed that cooling-based dehumidification system is more efficient than water absorption systems for radiant cooling because water absorption system should consume much energy for regenerating the heat absorption medium (Takehito et al., 1999). Desiccant dehumidification can be used with a mechanical ventilation system because it can catch the vapor infiltration from outdoor intake air and throw it into the exhaust air. However mechanical ventilation is not generally used in residential buildings, where cooling-based system is available.

To apply cooling-based dehumidification, for the room with low SHR, reheat process may be needed after overcooling for sufficient dehumidification. With the lower temperature of the heat exchange surface of dehumidification system, the lower SHR could be allowed. Considering the cooling production system composition, if the heat exchange medium of dehumidification system and radiant cooling panel could be supplied from the same source, that is, if commonly used chilled water is available without requiring a reheat process for the dehumidification system, which would be most efficient.

To determine the applicability of cooling based dehumidification system using general chilled water, the cooling load for whole cooling period and the SHR should be calculated when peak latent load occurs and examine whether the chilled water coils have the apparatus dew point under this conditions exist or not. Therefore, as the sample days for load analysis, the day with latent load peak (hourly peak occurred) and the day with highest latent load ratio (lowest SHR, hourly peak occurred) were selected. For estimating required capacity of the dehumanization system, total cooling load of these sample days and peak total load of whole cooling period were also analyzed. Selected sample days for load analysis are shown in Table 2.

Table 2. Sample days for load analysis

	SHR	Latent Load	Total Load
Hourly Peak Day	05 / 01 (Case 1)	07 / 22 (Case 2)	08/19 (Case 4)
Hourly Minimum Day	08 / 31 (Case 3)	05/01 (Case 1)	05 / 01 (Case 1)

3.2. Heat medium conditions for dehumidification

The dehumidification/sub-cooling system must remove latent load because floor radiant cooling panel can remove sensible load only. Also, dehumidification is available only when coil surface temperature is lower than air dew point temperature. The outlet air temperature of cooling-based dehumidifier can be found on the room SHR line from the inlet status point in psychrometric chart. Generally, a dry-bulb temperature of outlet air of HVAC system is in the range of 14℃~16℃ according to the refrigerants temperature (coil inlet water temperature 7℃ and coil outlet water temperature 12℃ for general HVAC systems in buildings).

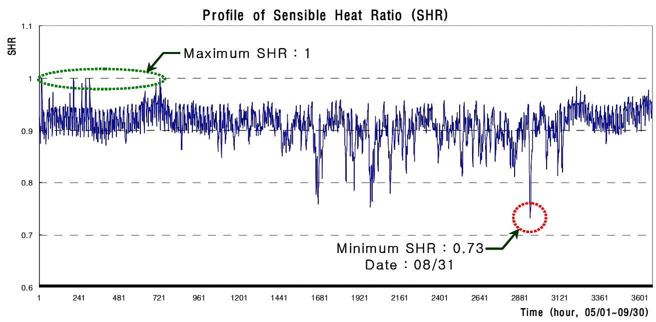

Figure 4. Room SHR during cooling period

Figure 4 presents profile of SHR from the simulation results during the whole cooling period and the minimum SHR is 0.73. Therefore, if we apply SHR 0.73 based on the state point (26℃, relative humidity 50%) of indoor air on the psychrometric chart, apparatus dew point temperature is defined at the point of about 11℃. This means that it can be possible for room to be dehumidified by a dehumidifier using general chilled water. In addition, it can be used that chilled water is produced in heat source for floor radiant cooling system.

3.3 Cooling load analysis for different load conditions

The cooling load characteristics of sample days to be selected were analyzed. Table 2 shows the results for four different cases classified by the amount and ratio of sensible load and latent load. Each case is a guide for estimating the capacity of cooling-based dehumidifier and basic operation strategy of combined cooling system (radiant cooling with dehumidification/sub-cooling system). It is described as following Table 3 and Table 4 that the amount and frequency of sensible and latent load during the whole cooling period.

Table 3. Profile of room sensible load

	0~10 W/㎡	10~20W/㎡	20~30W/㎡	30~40W/㎡	40~50W/㎡	50~ W/㎡
Frequency(hours)	2	747	1453	549	831	90
Percentage (%)	0.05	20.34	39.57	14.95	22.63	2.45

Table 4. Profile of room latent load

	0~2 W/㎡	2~4 W/㎡	4~6 W/㎡	6~8 W/㎡	8~10 W/㎡	10~ W/㎡
Frequency(hours)	1533	1424	588	96	26	5
Percentage (%)	41.75	38.78	16.01	2.61	0.71	0.14

3.3.1. Case 1 : Zero hourly latent load day (or Maximum SHR =1)

As shown in Figure 5, there is a case where the latent load did not occur because of low humidity ratio. Such case appeared in early May in the simulation. In this case, cooling load can be removed by only floor radiant cooling panel because the amount of sensible load is less than the maximum heat flow intensity of about 40W/㎡ (Rhie, 2003) of floor radiant cooling panel. If the increase of the latent load by internal heat gain is reduced, these periods will increase.

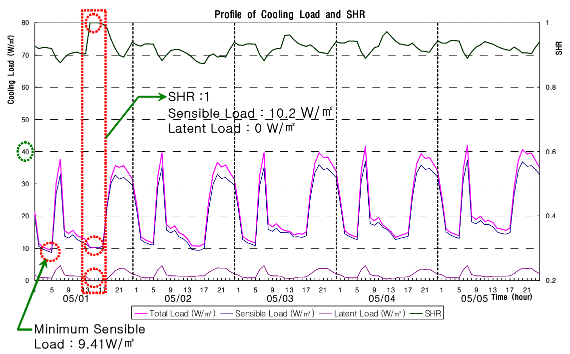

Figure 5. Zero latent load (maximum SHR)

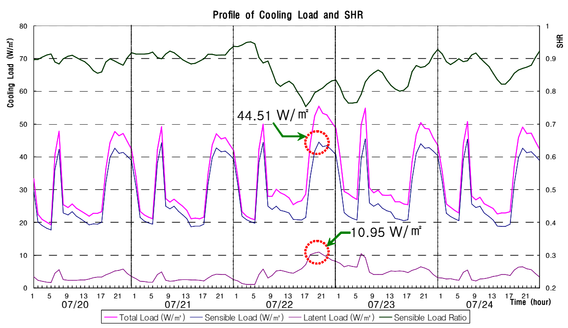

Figure 6. Room maximum latent load

Table 5. Profile of enthalpy (Room Latent Load = 0~2W/㎡)

	0~10 (kJ/kg)	10~20 (kJ/kg)	20~30 (kJ/kg)	30~40 (kJ/kg)	40~50 (kJ/kg)	50~60 (kJ/kg)	60~ (kJ/kg)	Total
Frequency(hours)	11	95	419	663	297	45	3	1533
% (whole cooling period)	0.30	2.59	11.41	18.06	8.09	1.23	0.08	41.76
% (Latent Load =0~2W/㎡)	0.72	6.20	27.33	43.25	19.37	2.94	0.20	100

There are many times when the latent load per unit floor area is less than 2W/㎡(41.75% during the whole cooling period, as shown in Table 4). If outdoor air conditions are favorable to be used as natural cooling, people may intend to remove cooling load through natural ventilation without cooling-equipment operation. Table 5 shows the periods that the enthalpy of outdoor air is lower than that of indoor set conditions (52.3 kJ/kg when 26℃DB, 50% RH). As shown, under low latent load conditions of less than 2W/㎡, for about 90% of these periods, the enthalpy of outdoor air is lower than that of indoor comfort conditions, In these situations, natural ventilation can be useful for indoor cooling

3.3.2. Case 2 : Maximum hourly latent load day

Figure 6 shows the case of maximum hourly latent load is occurred as shown in Figure 6, which was observed in July 22 in the simulation. In this case, not only latent load take the maximum value, but also sensible load take high value. At this time, the sensible load per unit floor area is 44.51W/㎡, which is 4.1 times as much as the latent load per unit floor area(10.95W/㎡). Figure 7, Figure 8 and Table 6 show the cooling coil performance generally used in HVAC applications in Korea. As shown, their treatment capability of sensible load is approximately 1.9~2.8 times as much as that of latent load (sensible heat factor 0.66~0.74). If this values are applied to the load simulation results, sensible load of about 13.85W/㎡ remain untreated. It should be removed although some sensible load removed through the cooling-based dehumidification system take full of their capacity for removing the maximum latent load. Thus, under these situations, the floor radiant cooling panel should be operated at once for removing residual sensible load while the dehumidification/sub-cooling system remove room latent load. For this case, the suitable heat capacity of dehumidification/sub-cooling system should be defined as the amount that it can remove the whole latent load.

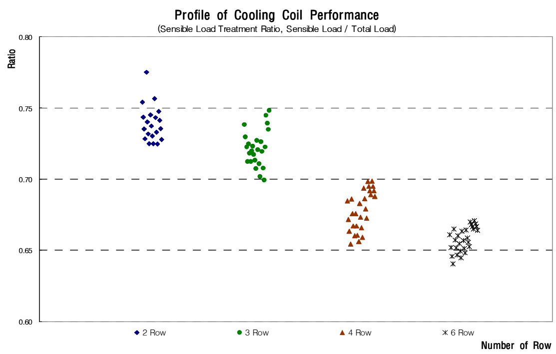

Figure 7. Profile of generally used cooling coil performance (sensible load / total load)

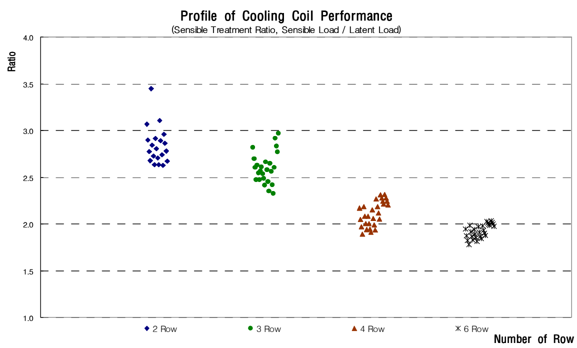

Figure 8. Profile of generally used cooling coil performance (sensible load / latent load)

Table 6. Cooling coil performance generally used in HVAC applications (average)

	2 Row	3 Row	4 Row	6 Row
Sensible / Total	0.739	0.722	0.678	0.658
Sensible / Latent	2.839	2.598	2.111	1.924

3.3.3. Case 3 : Minimum hourly SHR day

Figure 9 shows a case of minimum hourly SHR status as shown, which was observed in late August in the simulation. At this time, the latent load is relatively high compared to the other cases. The sensible load per unit floor area is 19.43W/㎡, which is 2.73 times as much as the latent load per unit floor area of 7.12W/㎡. According to the generally used cooling coil performance for HVAC systems, in this case, not only the room latent load but the sensible load also should be removed all when dehumidification/sub-cooling system is operated to dehumidify (2 Row in Table 6). Therefore, when latent load is much higher than sensible load (at least, room SHR is less than 2.83), especially when sensible load decreases dues the fact that no internal heat gain, use of solar shading or sudden latent load occurrences, all load can be removed by the dehumidification/sub-cooling system. Under these situations, floor radiant cooling panel need not be operated together to prevent over cooling.

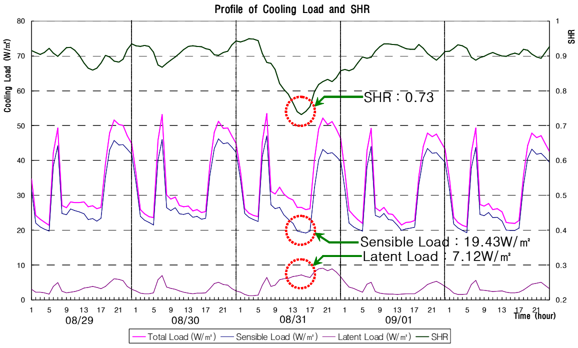

Figure 9. Room minimum SHR

3.3.4. Case 4 : Maximum hourly total load day and others

It is the most frequently occurring case where the sensible load is relatively much higher than the latent load. In this case, the floor radiant cooling panel and dehumidification/sub-cooling system should be operated at the same time to remove all cooling load. However, not to be over-cooled as the result of dehumidification operation, it is necessary for floor radiant cooling panel to remove only the residual sensible cooling load after subtracting the amount of total heat removed by the dehumidification system from room total cooling load. Figure 10 presents the maximum hourly total cooling load(56.86W/㎡) during the whole cooling period. If it is considered that sensible load is removed additionally when latent load is removed by the cooling-based dehumidifier, the residual cooling load can be fully removed by the floor radiant cooling panel. Moreover, under the conditions that the radiant floor cooling panel is not needed to be fully operated as its full capacity, the floor surface temperature can be further increased, making it advantageous to ensure comfort level of floor surface and to save energy. Table 7 presents residual sensible cooling load after dehumidifying.

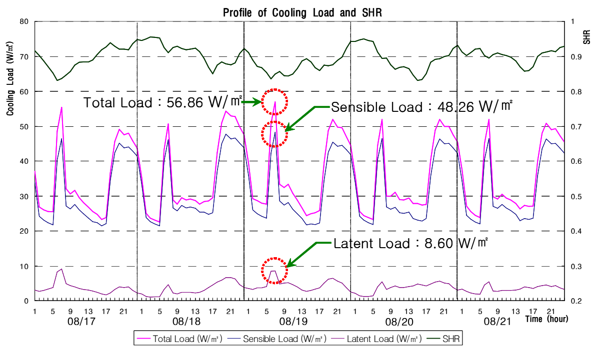

Figure 10. Room maximum total load

Table 7. Residual sensible cooling load after dehumidifying

	No requirement or Overcooling	0~10W/㎡	10~20W/㎡	20~30W/㎡	30~40W/㎡	40~ W/㎡	Maximum
2 Row	7 (0.19%)	254 (6.92%)	1895 (51.61%)	1191 (32.43%)	325 (8.85%)	0 (0.00%)	37.57 W/㎡
3 Row	6 (0.16%)	215 (5.86%)	1867 (50.84%)	1161 (31.62%)	423 (11.52%)	0 (0.00%)	38.49 W/㎡
4 Row	6 (0.16%)	133 (3.62%)	1803 (49.10%)	1051 (28.62%)	678 (18.46)	1 (0.03%)	40.35 W/㎡
6 Row	6 (0.16%)	109 (2.97%)	1776 (48.37%)	1001 (27.26%)	777 (21.16%)	2 (0.05%)	41.06 W/㎡