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An Occupant-Oriented Calculation Method of Building Interior Cooling Load Design

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Abstract: Given continued improvement in the thermal performance of building envelopes, interior disturbances caused by occupant behavior now have the greatest impact on building loads and energy consumption. The accurate calculation of interior load during design stage was emphasized in this paper, and a new method was proposed. Indoor occupants were considered as the core of interior disturbances, and the relationship with other interior disturbances was explored. The interior heat release was arbitrarily combined with the representative cooling load to be utilized in building cooling load calculation. Field surveys were conducted in three typical university buildings: an office building, a teaching building, and a library, located in a university in Tianjin, China. The oversized chillers supplying cooling for the buildings resulted from the over-estimating of the indoor occupant number and the power density of electric appliances. Through quantitative analysis, it was observed that the maximum representative interior loads were 196.43, 329.94, and 402.58 W/person, respectively, for the case buildings, at least 50% less than the empirical design data. Compared to the measured cooling load during the testing period, the accuracy of the modified cooling load was greater than 90%. This research is intended to serve as a reference for calculating and optimizing the design loads of cooling systems.

Keywords: load disturbances; representative interior load; consistency check; university buildings

1. Introduction

Buildings have been widely recognized as one of the main energy consumption sectors and the key to energy efficiency in the whole society [1]. Increasing demand for comfortable built environments has made the energy efficiency of heating, ventilating, and air-conditioning (HVAC) systems the primary objective in the non-residential sector [2]. In order to achieve energy efficiency in buildings, the design and optimization of HVAC systems are particularly important where the energy performance is affected by operational conditions, as well as heating and cooling needs. With the continuous improvement of building energy efficiency standards [3], the thermal performance of building envelopes has notably enhanced. Based on the demarcation of the building structure, three primary factors affect the energy consumption of the HVAC system: exterior disturbances, interior disturbances, and the operational factors of the energy supply system [4,5]. Exterior disturbances include outdoor air conditions and solar radiation. Interior disturbances include indoor occupants and the usage of electric appliances, such as lamps and equipment. Operational factors of the energy supply system include the energy efficiency of chillers, water pumps, and fans. Given the gradual improvement of the thermal insulation of building envelopes, the impact of exterior disturbances on the building cooling/heating loads has decreased. Interior disturbances relative to occupant behavior have now become the most important factors influencing building load and energy consumption, especially for the cooling condition [6].

The importance of interior disturbances, especially occupant behavior, has been raised attention in recent research. Escrivá-Escrivá [7] pointed out that energy behavior characterization and quantification were the first step towards the identification of actions to improve energy use, and a communication route should be established between users and building managers. Considering the diversity of occupant habits and physical and mental needs, it is difficult for researchers to analyze the nature of interior disturbances [8]. Yan et al. [9] overviewed the current state of occupant behavior modelling in building performance simulation, and obstacles were summarized. Four-step interactive process of modelling and applying the occupant behavior models, namely data collection, model establishment, evaluation, and simulation tools coupling, were outlined. Kwok and Lee [10] established an artificial neural network model for cooling load predictions and applied it to an office building in Hong Kong. It was observed that when precise occupant room rates were considered, prediction accuracy improved greatly. Escriva-Escriya et al. [11] proposed a three-step methodology, considering the occupant behavior on appliances, to simulate building loads and compared the measured results with the measured daily load curves for a typical workday and weekend. López-Rodrígue et al. [12] analyzed typical human activity in Spanish residential buildings based on Time Use Survey Data and established a stochastic model for predicting the dynamic occupancy rate.

Based on the above literature review, two targets are set for the occupant behavior modeling. One is to fill the gap between the simulated energy consumption and the actual usage data during operation phase. The other is to understand and optimize the control strategy of the energy supply of the HVAC system, the lighting, and the equipment. However, much emphasis has been placed on the optimization and regulation of system operation while ignoring the building load and unit capacity calculation during design stage. As cited by Nguyen and Aiello [13], occupant presence and behavior in buildings have been shown to have a great impact on space heating, cooling, and ventilation demand, and have the potential of one-third energy efficiency rate to a building's designed energy performance. Gunay et al. [14] overviewed the methodologies and challenges of studying the adaptive occupant behaviors. The emphasis of future works was suggested to be put on building and systems design. Gul and Patidar [15], however, proved that occupants had a small influence on the electricity consumption of buildings with high energy use intensity. The energy consumption of the HVAC system remains high even with decreased indoor occupancy rate because of too large system capacity design. So, the proper capacity design of the energy supply system is the premise of high energy performance of HVAC systems and the basis of holistic energy efficiency of a building [16] or multiple buildings in a zone [17].

The interior disturbances are generally considered in the cooling conditions at present [18]. In relative design standards, the interior disturbances are quantified for several building types based on empirical data [19,20]. The influence of the interior disturbances on the building cooling load is often overlooked during the design process [21]. In addition, the interior load disturbances are considered separately in the cooling load calculation [22]. However, indoor occupants have been proved to be the core of interior load disturbances [23,24]. In the above situation, the HVAC system is generally designed oversized because of the large cooling load. So, the relationships, influences, and detailed data of interior load disturbances should be reconsidered and quantified based on practical conditions.

In order to solve the above problems and achieve an optimal design cooling load, the interior cooling loads were reconfigured and the concept of representative interior load was explored in this study. Three typical university buildings: a teaching building, an office building, and a library, were selected as special cases. Quantitative analysis was implemented relative to interior disturbances, such as occupants and the behavior of electric appliances. The rest of the paper was organized as follows. The concepts of *load disturbance* and *occupant oriented representative interior load* were defined as the main methodology of the paper in Section 2. The modeling and estimation of the proposed interior load calculation method was established. Three typical university buildings, located in a zone cooling and heating supplied by ground source heat pumps, were selected as cases in the research with which to explore the nature of interior disturbances in various building types through field investigation and measurements during the cooling season (August and September) in 2017. In Section 3, characteristics of interior load disturbances of the case buildings were analyzed and quantified. The regularities of indoor occupant number and the relationships between lighting and equipment with indoor occupants were proposed through data fitting. The final description of the interior load disturbance was illustrated. The accuracy of the interior load calculation method was demonstrated in Section 4. The feasibility was proved through building cooling load simulation.

2. Methodology

2.1. Concept of Load Disturbances

The concept of *disturbances* comprises the variables that influence the indoor thermal environment. The nature of the indoor thermal environment is primarily determined by exterior and interior disturbances. Generally, the outdoor meteorological parameters, such as air temperature and solar radiation, are classified as exterior disturbances. Occupants, equipment, and lighting can be classified as interior disturbances. Though the thermal change in the indoor environment was caused by exterior air temperature, the window usage or fresh air volume is determined by occupants. So, the fresh air load cannot be strictly attributed to neither exterior nor interior factors. Therefore, fresh air induced from open windows is considered to be a special type of disturbance. Based on the above concepts, the building cooling load constitutes exterior disturbances, interior disturbances, and fresh air disturbances. So, the building cooling load can be calculated by

$$CL_{\tau} = CL_{ex,\tau} + CL_{f,\tau} + CL_{in,\tau} \tag{1}$$

Based on Equation (1), the building cooling loads are divided into three parts: the exterior cooling load, which is caused by exterior disturbances related to the building envelope and solar radiation; the fresh air load caused by the volume of fresh air, which is further related to the number of occupants, and the temperature differential between the inside and the outside of the building; and the interior cooling load, which is caused by heat gain due to interior disturbances.

The exterior cooling load can be easily calculated based on building load simulation software. The fresh air schedule, which is in direct proportion to occupant number, is the key to calculating fresh air load. The interior load calculation is the study object of this paper. So, the interior load can be calculated by

$$CL_{in,\tau} = CL_{\tau} - CL_{ex,\tau} - CL_{f,\tau} \tag{2}$$

2.2. Definition of "Representative Interior Load"

The interior cooling load is caused by heat release due to interior disturbances. In this paper, only readily discernable indoor factors that influence the building cooling load comprise the interior load, namely, indoor occupants, combined with the used lighting and equipment. The cooling load of interior disturbances can be calculated by

$$CL_{in,\tau} = \sum_{i} n_{i,\tau} \cdot q_{i,\tau} \cdot C_{i,\tau} \tag{3}$$

Based on Equation (3) [19,20], the time-varying number $n_{i,\tau}$ and the heat release $q_{i,\tau}$ of each load disturbance should be determined separately. It might be difficult if the usage information is not obtained clearly by the designers, especially the usage of lighting and equipment. Indoor occupant number is relatively easy to quantify if the building is used regularly. However, the usage of lighting and equipment is not independent of the indoor occupants. Because the usage of lighting and equipment is decided by the occupant control behaviors, some relationship must exist between the used lamp and equipment number with indoor occupant number, respectively. Based on the relationship, this paper proposed the occupant-oriented "representative interior load". Then, the calculation of interior load can be simplified as

$$q_{re,\tau} = \left(\varphi_{occ} \cdot q_{occ,\tau} + \lambda_{lig,\tau} \cdot E_{lig} + \sum_{eqpi} \lambda_{eqpi,\tau} \cdot E_{eqpi} \right) \cdot C_\tau \tag{4}$$

So, the interior load can be calculated by

$$CL_{in,\tau} = n_{occ,\tau} \cdot q_{re,\tau} \tag{5}$$

Comparing Equations (3) and (5), the indoor occupant number is the basis of interior load. The interior loads can be calculated by the heat release of occupants, used lamps, and equipment. The installed rated power of lamps and equipment is decided by building design. So, the key factors of calculating interior load based on Equations (4) and (5) are the indoor occupant number and the corresponding used lamps and equipment. The problem has been transferred to the quantifying of indoor occupant number and establishing the relationship of used lamps and equipment number with indoor occupant number. The detailed form and parameters should be determined by the following functions.

$$n_{occ,\tau} = f_{occ}(\tau) \tag{6}$$

$$\lambda_{lig,\tau} = \frac{n_{lig,\tau}}{n_{lig} \cdot n_{occ,\tau}} = \frac{f_{lig}(n_{occ})}{n_{lig} \cdot n_{occ,\tau}} \tag{7}$$

$$\lambda_{eqpi,\tau} = \frac{n_{eqpi,\tau}}{n_{eqpi} \cdot n_{occ,\tau}} = \frac{f_{eqpi}(n_{occ})}{n_{eqpi} \cdot n_{occ,\tau}} \tag{8}$$

2.3. Modeling and Uncertainty Estimation of Building Cooling Load

Based on the above analysis, the procedure of establishing the building cooling load model with the proposed representative interior load applied was shown as Figure 1.

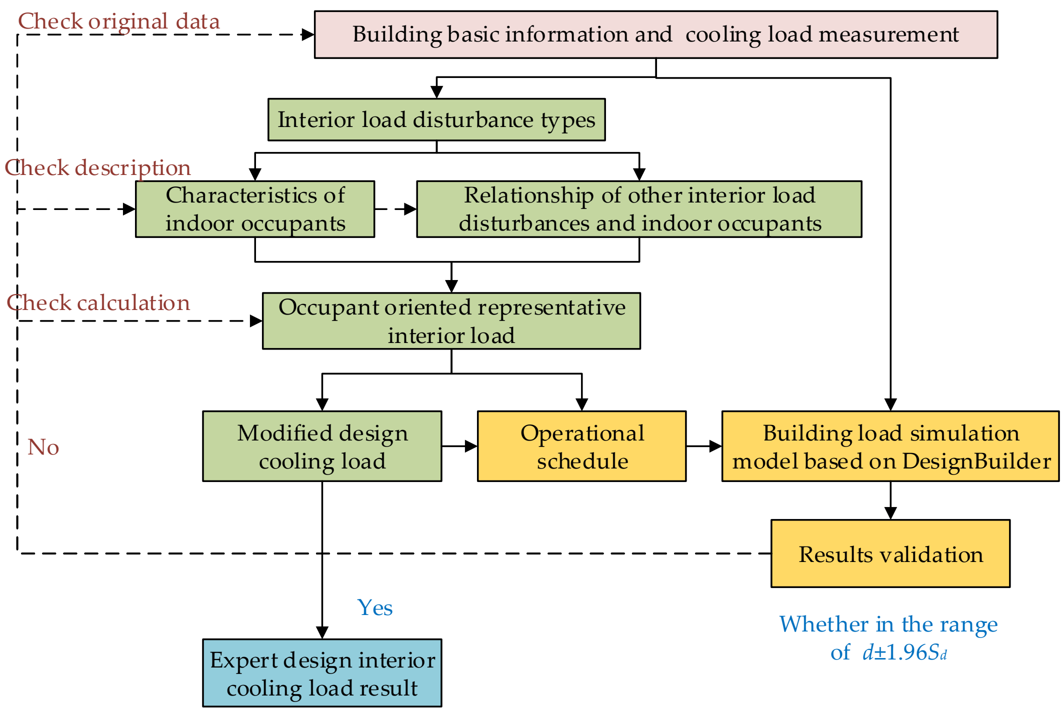


Figure 1. Occupant-oriented, representative interior load establishment and application procedure.

There are three parts in the method proposed in this paper.

(a) First one and the core is the interior cooling load calculation. Three relationships described in Equations (6)–(8) are the emphases. The relationships are formulated in the following sections based on the case study of three typical university buildings.

(b) The second part is the basic building cooling load simulation model based on the basic building information, such as building shape, envelope, etc., and indoor and outdoor meteorological parameters. In this paper, the building cooling load simulation models are established with DesignBuilder tool. DesignBuilder is dynamic simulation software that has a comprehensive builder graphical interface and uses EnergyPlus as core calculator [25,26]. The procedure of establishing a building load simulation model based on DesignBuilder is shown in Figure 2.

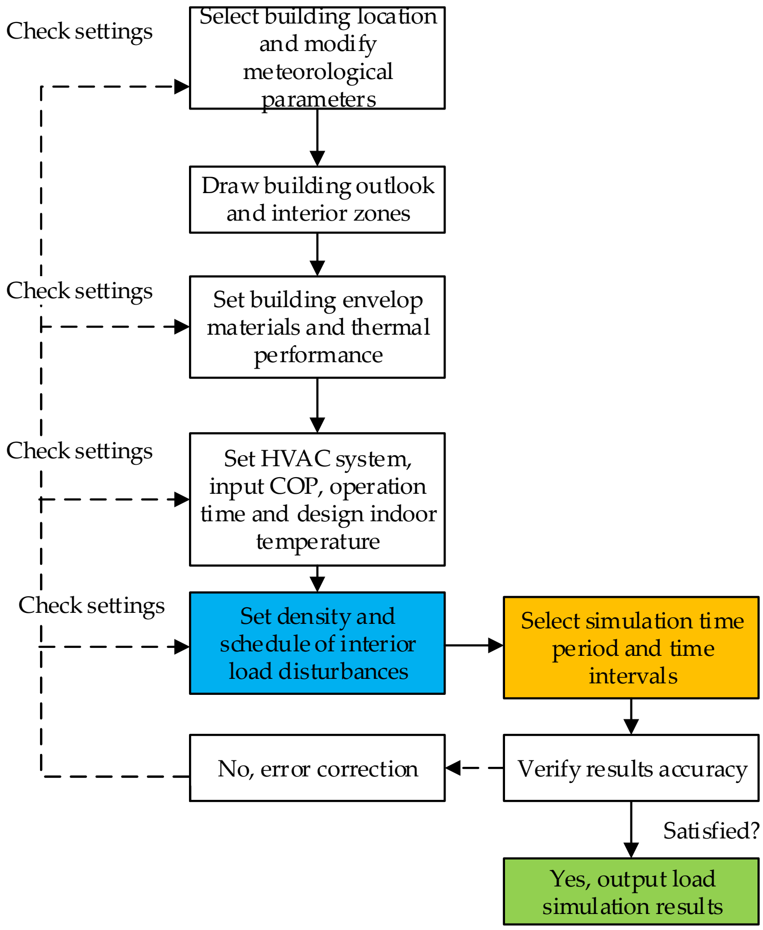


Figure 2. Flow chat of building load simulation based on DesignBuilder tool.

(c) The third part is the checking and verifying procedure. To verify the accuracy of simulated building cooling loads based on the representative interior load, the Bland-Altman plot method is applied to compare simulated building cooling loads with the measured actual loads. The verification parameter is [27]

$$S_d = \sqrt{\frac{1}{k-1}\sum_{i=1}^{k}(d_i - d)^2} \tag{9}$$

In general, if the number of points within the bounds of the range of consistency ($d \pm 1.96S_d$) accounts for more than 95% of the total points, it can be concluded that the two groups of values have good consistency.

2.4. Case Study

2.4.1. Basic Information

Three typical university buildings located in a university in Tianjin, China were selected as special cases with which to study the interior load characteristics of various building types. The buildings, together with other four similar teaching buildings, are cooling supplied by a zone energy station. The total covered building area of the energy station was 127,665 m^2. The main chillers of the energy station are 6 water source heat pumps (WSGP) with a cooling capacity of 19,200 kW. The design cooling load is 142.02 W/m^2. The basic information of case buildings is shown in Table 1.

Table 1. Basic information of case buildings.

Building Type	Building Function	Building Area	Floor	Story Height	Orientation	Operation Time	Usage Rate
Office building	Administration offices in the 1st and 2nd floor, scientific research rooms in 3rd floor	3690 m^2	3	3.0 m	South	6:30–22:30; working time: 8:30–16:30	Office rooms occupy 80% building areas, others are meeting rooms, machine rooms, and corridor
Teaching building	Taking class and self-studying	6340 m^2	4	4.5 m	South	6:30–22:30	Classrooms occupy 80% building areas, others are machine rooms and corridor 80%
Library	Reading, borrowing and returning books, self-studying	41,410 m^2	4	4.5 m	South	8:00–22:00	Book reading area occupy 80%, others are special used rooms, hot water rooms, and machine rooms
Exterior views	 The office building			 Teaching building		 Library	

The design of building envelope and the thermal performance of case buildings were listed in Table 2.

Table 2. Building envelope thermal performance design information of case buildings.

Case Building	Heat Transfer Coefficient (W/(m^2·K))			Glass		Sun-Shading Type	Window to Wall Ratio				
	Exterior Wall	Roof	Exterior Window	Solar Heat Gain Coefficient	Visible Transmittance		S	W	E	N	Inner Side
Teaching building	0.580	0.480	2.590	0.592	0.428	Curtains	0.80	0.30	0.30	0.80	/
Office building	0.550	0.480	2.260	0.505	0.720	Horizontal shutters	0.60	0.05	0.55	0.65	0.90
Library	0.550	0.480	2.200	0.505	0.720	Horizontal shutters	0.90	0.90	0.90	0.90	0.90

The construction drawings and load design documents for buildings were examined. The design conditions of interior load disturbances of case buildings are listed in Tables 3–5, respectively.

Table 3. Design information of the interior load disturbances of the teaching building.

Item	Content	Item	Content
Room type	Class room	Number	30
Average area (m^2)	209	Full-check occupant number	200
Installed lamps			
Average lamps per room	32	Rated power (W)	28
Equipment information			
Equipment1	Computers	Number per room	1
Equipment2	Projectors	Number per room	1

Table 4. Design information of the interior load disturbances of the office building.

Item	Content	Item	Content
Small office rooms			
Room type	Administration offices	Full-check occupants (number per room)	1–2
Average area (m^2)	23	Number	5
Electrical appliances			
Lamps (number per room)	4	Rated power (W)	24
Computers (number per room)	1–2	Rated power (W)	300
Printers (number per room)	1	Rated power (W)	250
Water dispenser (number per room)	1	Rated power (W)	500
Median office rooms			
Room type	Administration offices	Full-check occupants (number per room)	5
Average area (m^2)	54	Number	6
Electrical appliances			
Lamps (number per room)	8	Rated power (W)	24
Computers (number per room)	5	Rated power (W)	300
Printers (number per room)	1	Rated power (W)	250
Water dispenser (number per room)	1	Rated power (W)	500
Shredders (number per room)	1	Rated power (W)	135
Large office rooms			
Room type	Research rooms	Full-check occupants (number per room)	16
Average area (m^2)	115	Number	6
Electrical appliances			
Lamps (number per room)	26	Rated power (W)	24
Computers (number per room)	16	Rated power (W)	300
Printers (number per room)	1	Rated power (W)	250
Water dispenser (number per room)	1	Rated power (W)	500
Shredders (number per room)	1	Rated power (W)	135
Projectors (number per room)	1	Rated power (W)	350

Table 5. Design information of the interior load disturbances of the library.

Appliances		Number	Rated Power
Lamps	Type1	2743	11
	Type2	328	36
Computers		50	300
Multiple function printers		8	2000
Printers		4	250
TVs		30	73

The maximum interior heat release of electric appliances under design conditions are 157.39, 177.76, and 72.43 W/m^2 in the teaching building, the office building, and the library, respectively, based on

Tables 1 and 3–5. The values are extremely different with the generally used recommended data in Ref. [20] listed in Tables 8 and 9 for the teaching building and the office building. The proportion of occupants, lighting, and equipment is different because of various building types. In the two buildings, the occupant and equipment heat releases take more than 90% of the total heat release. In the teaching building, the ratio of occupant, lighting, and equipment is about 42:3:55. The ratio of the office building is 12:8:80. However, in the library, the heat release of occupants is the main part, taking the proportion of 96.65%. It indicates that the over design value of occupants and equipment will result in the over estimating of cooling loads.

2.4.2. Building Usage Data Collection

Various methods, including static [28] and dynamic [29] methods, were adopted in research to obtain building usage data, especially occupant-related information. After Ekwevugbe et al. [30] measured the occupancy in non-domestic buildings and added the information to the building management system. CO_2 sensors and passive infra-red (PIR) detectors were explored. Cameras were also used in automatic monitoring [31]. However, it is really difficult to transform the video information to digital data. So, field survey and infra-red counters were adopted in this paper to obtain the indoor occupancy data. The picture of infra-red counter was shown in Figure 3.

Figure 3. The picture of infra-red counters.

The usage information of lamps and equipment can also be obtained by field survey. However, for office buildings with relatively private office rooms, the cameras were installed for field monitoring of key office rooms. Two multiple-occupant offices, an administration office and a scientific research office, were selected as examples to represent the usage information of the two types of office rooms. In addition, rooms occupied or not were recorded one by one through on-site survey in the office building.

The time interval of data record was 1 h. The investigation was conducted for two time periods, August 1st to 15th 2017 and September 1st to 15th 2017, respectively. The cooling period of Tianjin is from June 15th to September 15th. The first survey period is generally the hottest days during the year; however, it is during summer holiday. The second investigation period is the relatively cool days and was one week after fall opening in 2017. So, the two time periods of August 1st to 15th 2017 and September 1st to 15th 2017 were recognized as holidays and general used period, respectively.

In order to validate the proposed interior cooling load calculation method, the actual cooling load should also be measured. To calculate the actual cooling load, the outdoor meteorological parameters, indoor air temperature, and cooling capacity were tested at the same time. The outdoor meteorological parameters, including temperature, solar radiation, air speed, indoor temperature, and cooling energy consumption, were measured. Test instruments installed in the three buildings included HOBO U10-003 thermographs (temperature accuracy range ±0.4 °C), relative humidity accuracy range ±5%), UT-230A dynamometer (accuracy range ±0.01 W), infrared thermometer (accuracy range ±1.5%), anemometer (accuracy range ±0.01 m/s), and AZ-8778 black bulb thermometer (accuracy range ±0.8 °C). The test interval was set to 10 min to avoid missing data. U10-003 thermographs and flow meters were installed on the inlet and outlet pipes of buildings to measure the cooling capacity.

Data during August 1st to 7th and September 1st to 7th was adopted to analyze the characteristics of interior cooling load and quantify the representative interior cooling load in Sections 3 and 4.1, Sections 4.2 and 4.3. The other part of data was used to validate the proposed method and results in Section 4.4.

3. Characteristics Analysis of Interior Load Disturbances

3.1. Indoor Occupants Analysis

The variation of cooling load originated from the energy demand change of occupants. Indoor occupant number is the premise of the perspective interior load. Several approaches were adopted in building occupant modeling. Widen et al. [32] combined the Markov chain and bottom-up approach to model the indoor occupancy rate and the lighting demand. Andersen et al. [33] applied an inhomogeneous Markov chain to described the indoor occupancy rate of an office building located in San Fransisco. Two states, namely, high and low occupancy rate, were defined and described separately. The aggregated performance was verified for occupants on the building level. Some research only focused on the presence/absence state of occupants. Based on the hypothesis of a certain value of indoor occupant number, the arrival and departure times were selected as key times interrupting the presence state of occupants. J. Page et al. [34] proposed stochastic models for private offices and multiple-occupant offices, respectively. All this research considered the indoor occupant number as a stochastic parameter. However, the results of stochastic analysis proved that a steady probability, namely, the average condition, existed in the indoor occupant number or indoor occupancy rate for a long time for regularly used buildings. So, the average time-varying indoor occupant number was taken as the object in this paper to generate the schedule of indoor occupants, and data fitting approach was adopted.

If the indoor occupant number can be obtained directly and conveniently, the measured data will be the most accurate original data. Because the form of schedule is the easiest way to combine occupant behavior and building load simulation software [35], the measured data based on building on-site survey and infrared counters was adopted to be analyzed. The key to accurate modeling is the time interval of measured data. If the time interval is too small, the data amount will increase, and quantifying will be more difficult. However, if the time interval is too large, the validation will be doubted. The time intervals of relative research vary from 5 min to hours [36,37]. In order to explore the proper time interval of indoor occupant data, data fitting with different time intervals was explored in a multiple-occupant (full-check occupant number ≥ 8 [38]) scientific research office. The description of proper time interval should satisfy the acceptable goodness of fit (R^2), which, in general, is no less than 0.9 [39]. The measured indoor occupant data with time interval of 10 min was shown in Figure 4.

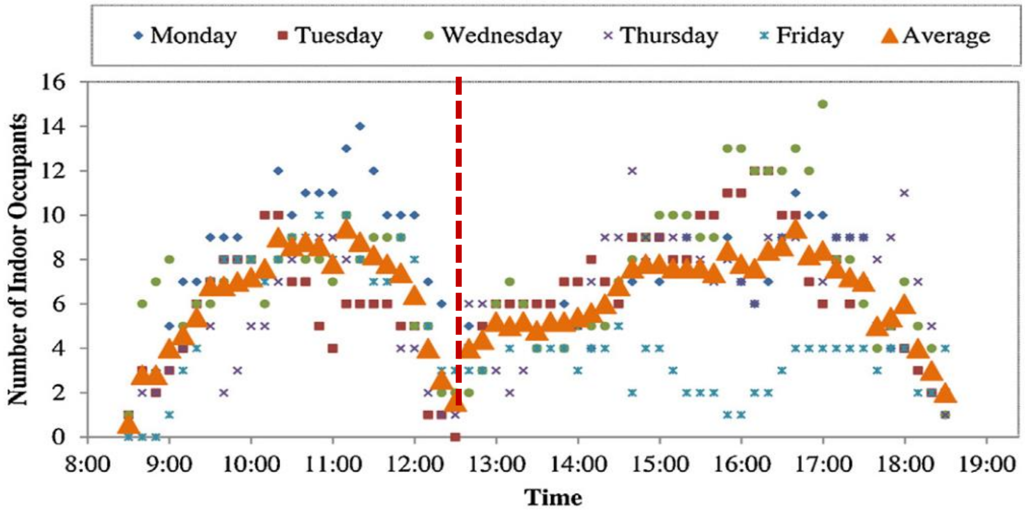


Figure 4. Time-varying indoor occupant number of a multiple-occupant office.

A bimodal distribution of the indoor occupant number with time was shown in Figure 4. The division was the lunch time. Data fitting with time intervals of 5 min, 10 min, 30 min, and 1 h was conducted, respectively, for the average time-varying indoor occupant number. The indoor occupant number in two time periods is in accordance with quadratic polynomial. The coefficients of fit goodness were listed in Table 6.

Table 6. Goodness of fit of quadratic polynomials.

R^2	8:30–12:30	12:30–18:30	13:30–18:30	12:30–17:30
5 min	0.9355	0.7615	0.8867	0.8415
10 min	0.9355	0.7542	0.8869	0.8652
30 min	0.9601	0.8275	0.9085	0.8892
1 h	0.9609	0.9258	0.9258	0.9720

Based on the results in Table 6, 1 h can be considered as the proper time interval for the quadratic polynomial based on the following reasons. R^2 is higher than 0.9 in the morning period, namely, 8:30–12:30, under all time intervals. However, R^2 is lower than 0.9 under 30 min time interval, though it is higher than 0.9 under the time interval of 1 h during 12:30–18:30. It means some fluctuations are hidden in 1 h. In order to find the fluctuations' present time, data during 13:30–18:30 and 12:30–17:30 were refitted. It turns out that the goodness of fit of quadratic polynomials under 4 time intervals are raised, especially in 13:30–18:30. So, the occupant number during lunch time is more stochastic than at other times. However, because the indoor occupant number is relatively low, the design cooling load will not be affected. So, the proper time interval for obtaining indoor occupant number was deemed as 1 h.

The measured, time-varying occupant number of the case buildings is in accordance with a trimodal distribution. The so called "trimodal distribution" means there are three maximums in different time periods of the hourly indoor occupant values. The key difference between occupant number of university buildings and that of the general office buildings is the usage during evening period. Many occupants use buildings in the evening. Particularly, the indoor occupant number of library in the evening is similar to or even more than that during the afternoon period.

Based on the above analysis, the quadratic polynomials with 1 h time interval as the input parameter are the proper relationship with which to describe the trimodal distribution of indoor occupant number. The function form is

$$n_{occ,\tau} = a_{occ}\tau^2 + b_{occ}\tau + c_{occ} = \begin{cases} 0 & t \in 0:00 - 6:30 \\ a_m\tau^2 + b_m\tau + c_m & t \in 7:30 - 12:30 \\ a_a\tau^2 + b_a\tau + c_a & t \in 13:30 - 17:30 \\ a_n\tau^2 + b_n\tau + c_n & t \in 18:30 - 22:30 \end{cases} \tag{10}$$

3.2. Lamps Usage Analysis

The lamps in the teaching building and the office building are available to be controlled by the occupants. The used lamp number was obtained by on-site survey.

As shown in the Figure 5, the regulation of the number of lamps that change with time is similar, though the number of lamps in use is different each day. In the teaching building, the number of lamps in use is escalated over time, while the number decreased slightly at lunch time and sharply at night in the office building. The usage habit varies for occupants in different buildings. So, the time-varying number cannot describe the control rule of lamps for all buildings. The relationship of lamps usage with indoor occupants should be explored.

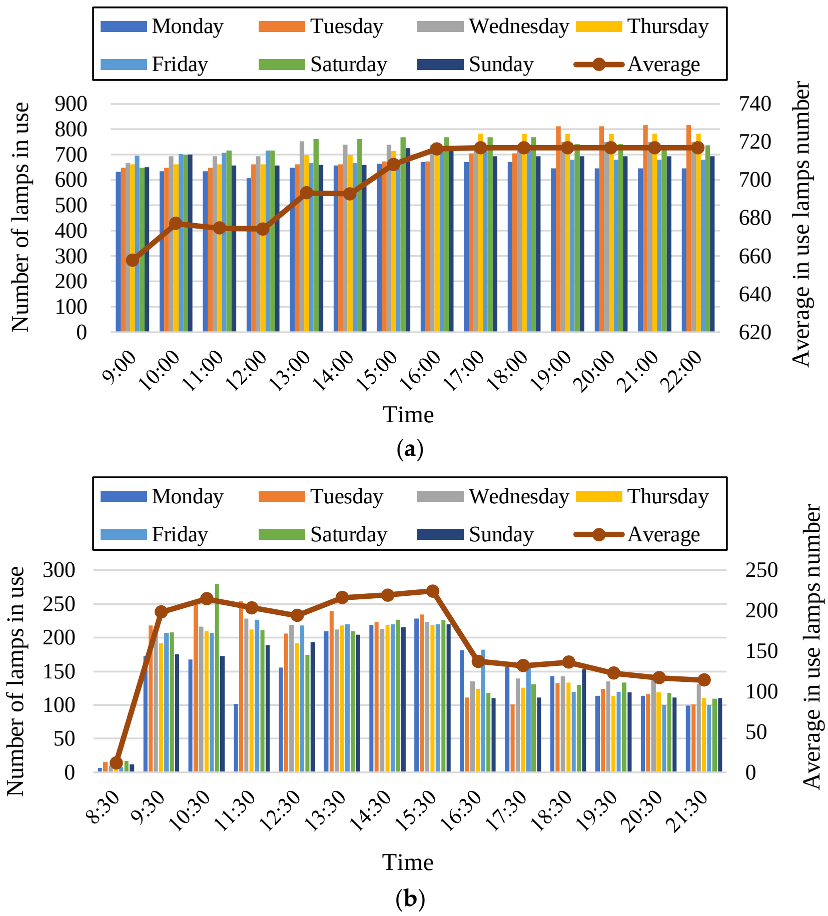


Figure 5. Number of lamps in use in the teaching building and office building. (**a**) Teaching building; (**b**) Office building.

Among the three case buildings, lamps installed in the library are unified switched on or off by an automatic controller. The lighting control strategy, namely, the usage rate of the installed lamps for all the operational days, is shown in Figure 6.

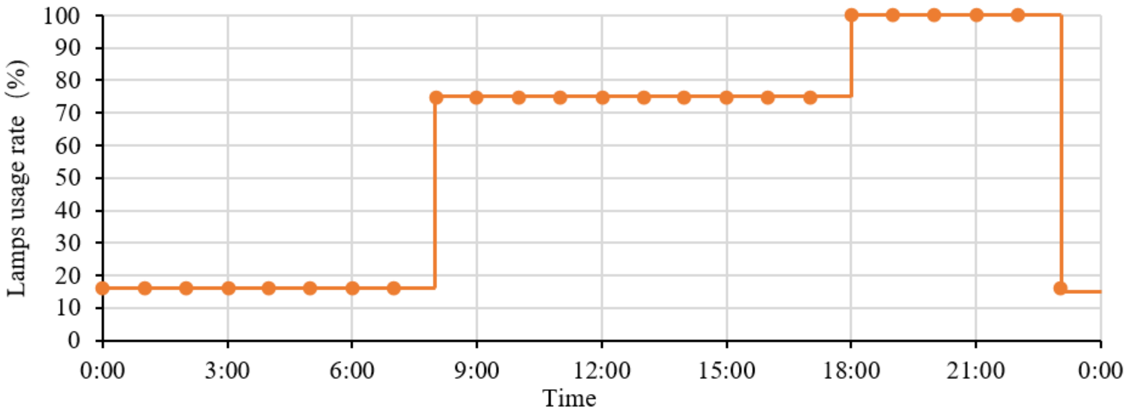


Figure 6. Time-varying rate of lamps in use of the library.

The installed lighting density of the library is 7.67 W/m^2. As shown in Figure 6 75% of the lamps will be switch on at 8:00, and this will increase to 100% at 18:00. 12% lamps remain in use for security reason at night.

Above all, for buildings in which the lamps are controlled by occupants, the in-use number is generally varying with indoor occupant number. For buildings, such as the library, in which the lamps are controlled by automatic center, the in-use number is decided by the control strategy.

3.3. Equipment Usage Analysis

The installed equipment in the teaching building and the library were listed in Tables 4 and 5, respectively. Only one computer with one projector and screen are used in an in-class room. Occupants can use laptops when self-studying. The equipment heat release when self-studying is determined by the simultaneously used laptops in the teaching building and the library.

Though the computers and laptops are the main equipment, other equipment will be used:

(1) Electrical boilers are installed in hot water rooms in the teaching building. Because the machine rooms are not air-conditioned, the heat release will not be accounted into interior loads.
(2) The booking borrowing and returning machines are computers in essence and are used in the operational time of the library. There are 6 managers working in the library. Everyone uses a computer when working. The TVs in the library are always on and printers are generally on standby.
(3) Guests generally do not use equipment in the office building. Computers are installed for both administration and scientific research occupants. However, laptops might also be used by scientific research workers. The probability was tested as 5%.

Based on the above analysis, the trimodal distribution pattern of the occupant number is consistent with the rules of building energy consumption [37]. So, the usage pattern of electric appliances, generally lamps and equipment, is considered to have certain relationships with indoor occupants. In Section 4, the relationship of indoor occupants with other interior load disturbances is discussed after modeling the indoor occupant number in Section 4. The quantification of representative interior load can be calculated.

4. Results and Discussion

4.1. Indoor Occupant Number Modelling

4.1.1. Classification of Indoor Occupants

Different occupants may cause different interior load. Based on this criteria, the indoor occupants should be categorized in case buildings:

(1) For the teaching building, students taking class only use lamps and teaching projection equipment, such as computers and projectors. About 50% of lamps and a computer and projector are generally used in an in-class room, while for self-studying students, the teaching projection equipment is not allowed to be turned on. Laptops can be used.
(2) For the office building, three types of occupants were classified, namely, the occupants working in the scientific research offices, occupants working in the administration offices, and guests. The on-duty time of occupants working in administration offices is fixed, while it is flexible for occupants working in the scientific research offices. Guests only come to the office building during on-duty time (8:30–16:30).
(3) For the library, three types of occupants were classified. The book managers in the library are responsible for books borrowing and returning. Students that come to the library to borrow and return books are the second type. The third type of occupants is the self-studying students. Personal mobile computers, namely, laptops, can be used.

Based on this classification, the occupant number was investigated for each type of occupant of the case buildings. For the teaching building, the hourly indoor occupant number of each room was investigated. For the office building, the total indoor occupant number was tested hourly, and the usage information was recorded based on building patrolling. For the library, the total indoor occupant number was investigated hourly both based on infrared counters and building patrolling. Thus, the different types of indoor occupants can be counted hourly. The average occupant numbers were analyzed in Section 4.1.2. Based on the time series of types of indoor occupants, the used appliances were analyzed in Section 4.2.

4.1.2. Time-Varying Indoor Occupant Number

(1) Teaching building

For the teaching building, because the rooms that are in class are different during the week, the occupant number of the teaching building varies during general used period. However, the used light and equipment number is not related to the indoor occupant number if a room is in-class, so the in-class room number and the occupant number of self-studying were recorded during field investigation (shown in Figures 7 and 8 respectively). The average indoor occupant number per room during holidays is shown in Figure 9.

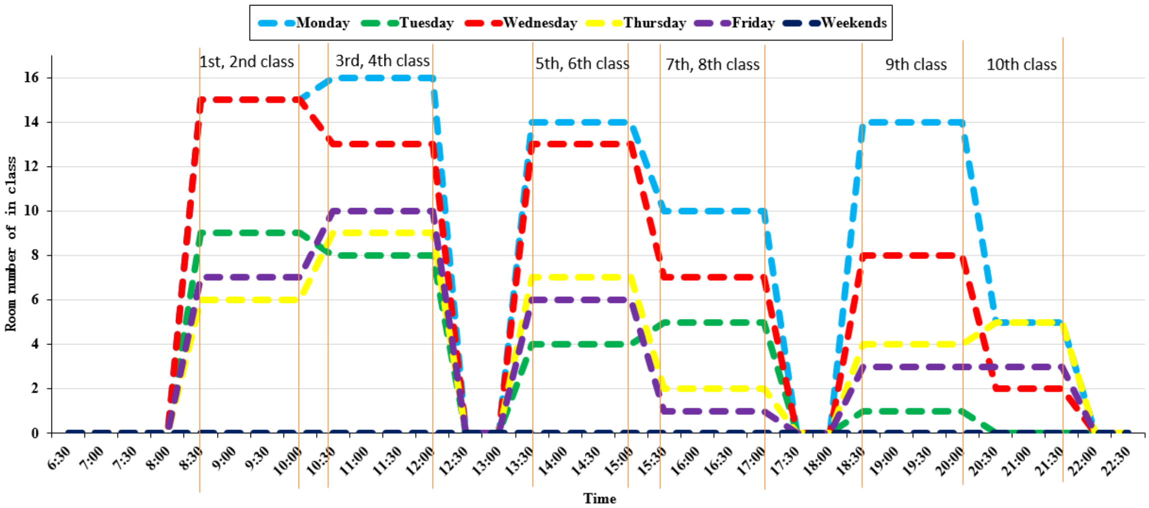


Figure 7. In-class room number of the teaching building during a week.

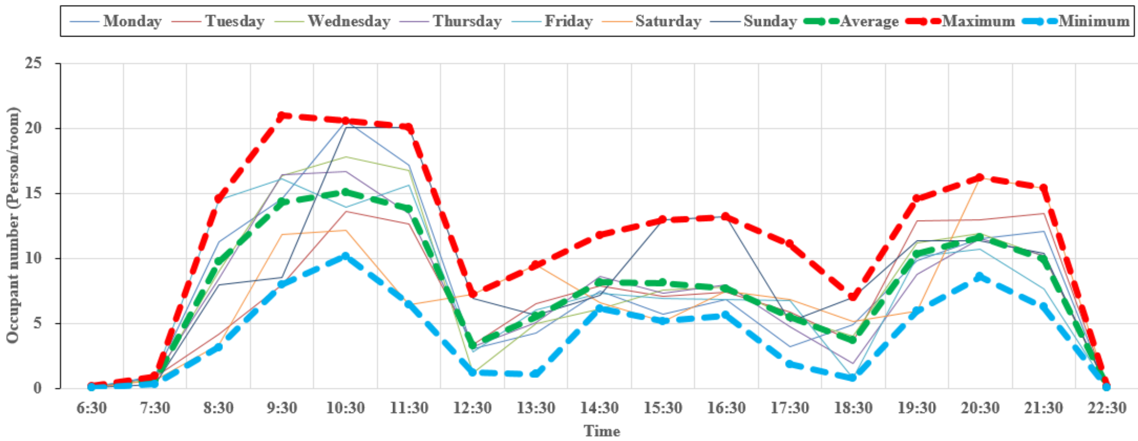


Figure 8. Measured occupant number of self-studying students in teaching building.

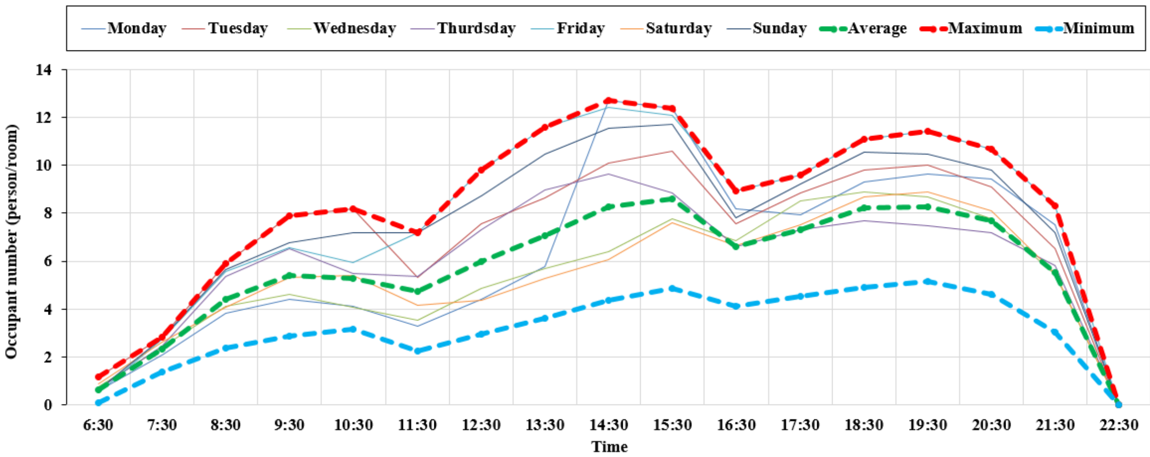


Figure 9. Measured indoor occupant number of the teaching building during holiday.

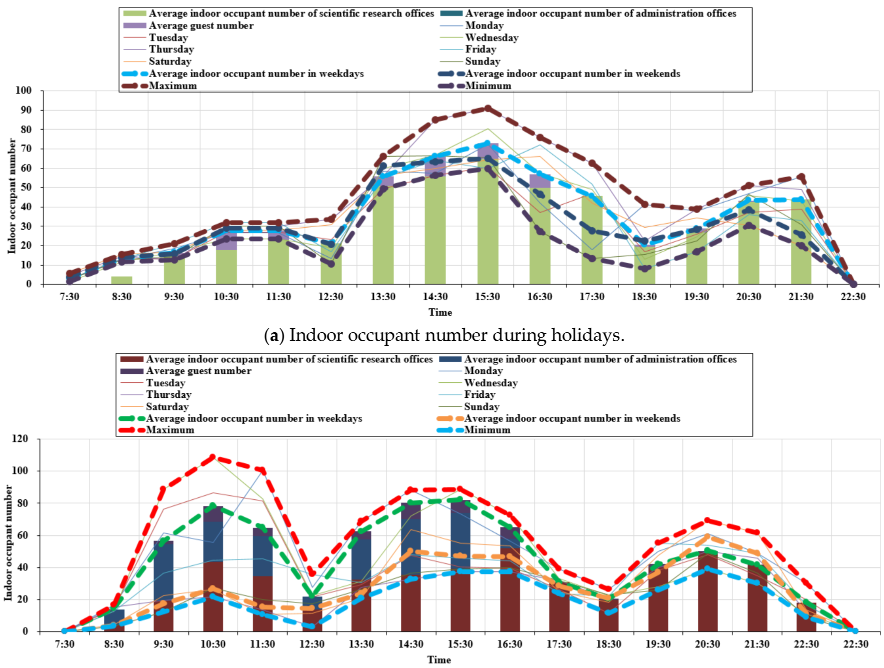
As illustrated in Figures 8 and 9, the indoor occupant number can be divided into three time periods. So, the relationship of indoor occupant number with time of the case teaching building can be illustrated as

$$
\begin{aligned}
n_{occ,cls.\tau} &= n_{se,cls.\tau} + \sum n_{inc,cls.\tau} \\
&= \left(a_{occ}\tau^2 + b_{occ}\tau + c_{occ}\right)_{se,cls.} \times \left(n_{cls} - n_{inc,cls}\right) + n_{inc,cls.\tau}{}' \times n_{inc,cls} \\
&= \begin{cases} 0 & t \in 0:00 - 6:30 \\ \left(a_m\tau^2 + b_m\tau + c_m\right)_{se,cls.} + 50 \times n_{inc,cls} & t \in 7:30 - 12:30 \\ \left(a_a\tau^2 + b_a\tau + c_a\right)_{se,cls.} + 50 \times n_{inc,cls} & t \in 13:30 - 17:30 \\ \left(a_n\tau^2 + b_n\tau + c_n\right)_{se,cls.} + 50 \times n_{inc,cls} & t \in 18:30 - 22:30 \end{cases}
\end{aligned}
\tag{11}
$$

(2) Office building

Based on the analysis of indoor occupants in the teaching building, the emphasis should be put on the time-varying indoor occupants of different types that were divided. For the office building, rooms can be classified as administration rooms, scientific research rooms, and meeting rooms. As shown in Figure 2, the indoor occupant number of offices can be described as quadratic polynomials divided by time periods. There are 6 scientific research offices in use with the full-check occupant number of 96. 11 administration offices are used with the full-check occupant number of 39. The number of administration workers is 35. The general working occupants in administration rooms are fixed during working days and are 0 during weekends and holidays. A little variation might occur because of the arrival and department time, meetings, or business trips. The occupant number of scientific research rooms is various because of flexible working time. The guest number can be determined by calculating the difference value of total occupant number counted by the infrared counters and the estimated indoor occupant number of administration and scientific research offices. Only one meeting room is installed for one floor in the case building and is seldom used.

Based on the above division methods, the indoor occupant number analyzing results of the office building is shown in Figure 10.



(**a**) Indoor occupant number during holidays.

(**b**) Indoor occupant number during general used period.

Figure 10. Results of the indoor occupant number analysis of the case office building. (**a**) Indoor occupant number during holidays; (**b**) Indoor occupant number during general used period.

As shown in Figure 10, only scientific research workers use the offices during weekends and holidays. However, the occupant number in weekends is less than that of holidays, because some of the postgraduate doctoral and master students are still working during summer holidays. In addition, scientific research workers tend to work in the office building on holidays because of quiet work environment. The scientific research workers are more than the administration workers during weekdays. The time-varying schedule of administration workers is fixed during weekdays. Guests are a relatively small amount of occupants in the office building, less than 5% of the total indoor occupant number. So, the emphasis of indoor occupant in the office building should be put on the scientific research occupants.

Based on the above analysis, the indoor occupant number of the office building can be described as

$$\begin{aligned} n_{occ,off.\tau} &= n_{ad.,off.\tau} + n_{sc.,off.\tau} + n_{gu.,off.\tau} \\ &= \left[\left(a_{occ}\tau^2 + b_{occ}\tau + c_{occ} \right)_{ad.,off.} + \left(a_{occ}\tau^2 + b_{occ}\tau + c_{occ} \right)_{sc.,off.} \right] \times 1.05 \end{aligned} \tag{12}$$

The time periods are same with the divisions of the teaching building.

(3) Library

The indoor self-studying occupant number of the library is similar to that of the teaching building. The difference of total indoor occupant number counted by the infrared counters and the self-studying occupant number investigated by building patrolling is the borrowing and returning occupant number. The six book managers are not counted anymore. The time-varying occupant number during holidays and in the general used period of the library are shown in Figure 11.

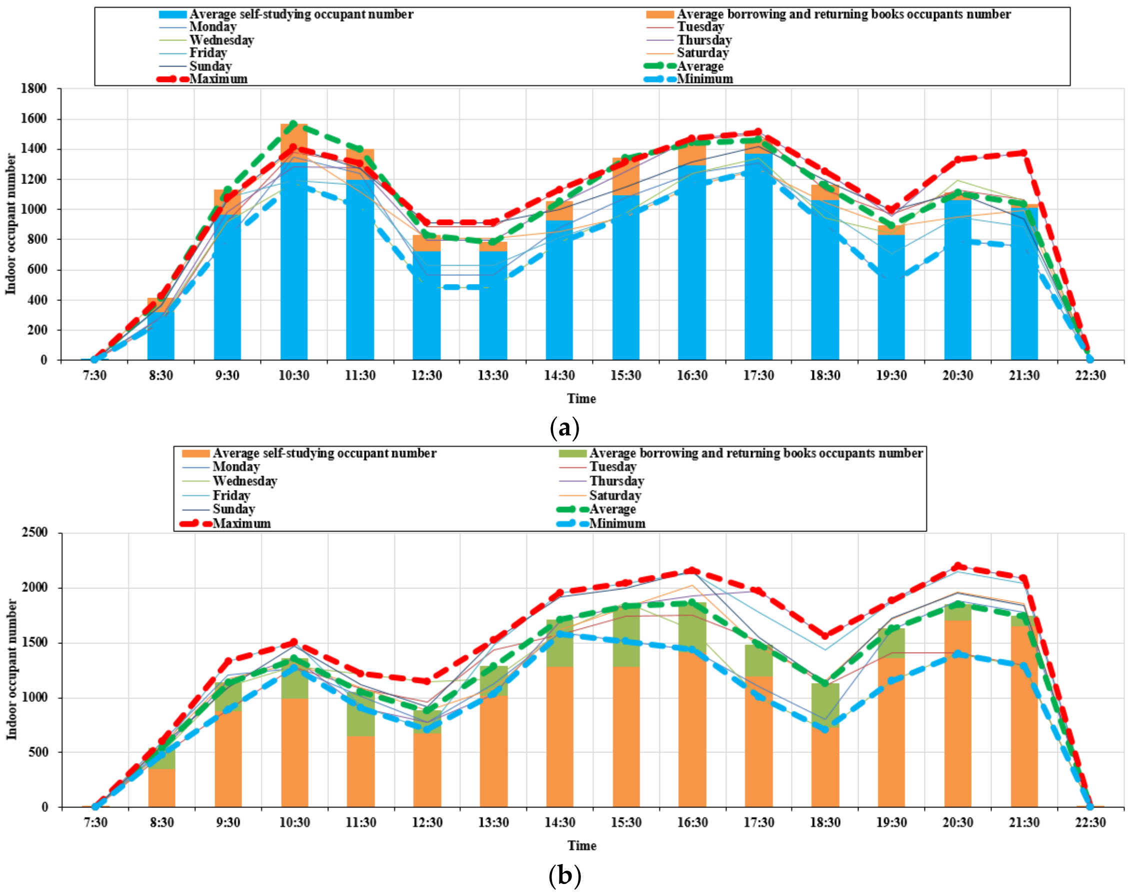


Figure 11. Results of the indoor occupant number analysis of case library. (**a**) Indoor occupant number during holidays; (**b**) Indoor occupant number during general used period.

The indoor occupant number of general used period of the library is much more than that of holidays, both the self-studying and the borrowing and returning books occupant number. The borrowing and returning books occupant number is generally fixed at about 140 during holidays and 330 during the general used period, respectively. The self-studying occupant number varies with time. The distribution pattern is consistent with the quadratic polynomials, shown in Figure 5.

Based on the above analysis, the indoor occupant number of the office building can be described as

$$n_{occ,lib.\tau} = n_{se.,lib.\tau} + n_{br.,lib.\tau} + n_{ma.,lib.\tau} = \begin{cases} \left(a_{occ}\tau^2 + b_{occ}\tau + c_{occ}\right)_{se.,lib.} + 140 + 6 & holidays \\ \left(a_{occ}\tau^2 + b_{occ}\tau + c_{occ}\right)_{se.,lib.} + 300 + 6 & general\ used \end{cases} \quad (13)$$

Based on the analysis of indoor occupant number of the three case buildings, the quadratic polynomials divided by time periods are suitable to describe the number of all the types of occupants. The independent variable is time, with a time-step of 1 h. The goodness of fit R^2 is generally above 0.9, which satisfies the accuracy requirement. Constant value can be recognized as a special form of quadratic polynomial. Based on the characteristics of indoor occupant number, the occupant-oriented representative interior load can be calculated based on the relationship of lamps and equipment in use with indoor occupants.

4.2. Relationship of Lamps and Equipment in Use with Indoor Occupants

4.2.1. Relationship of Lamps in Use with Indoor Occupants

The relationship between lamps usage and indoor occupants was analyzed based on occupant types:

(1) Teaching building

In in-class rooms, generally 50% of lamps are used because of the usage of projector and screen. In self-studying rooms, the corresponding average of used lamps and indoor occupant number is shown in Figure 12.

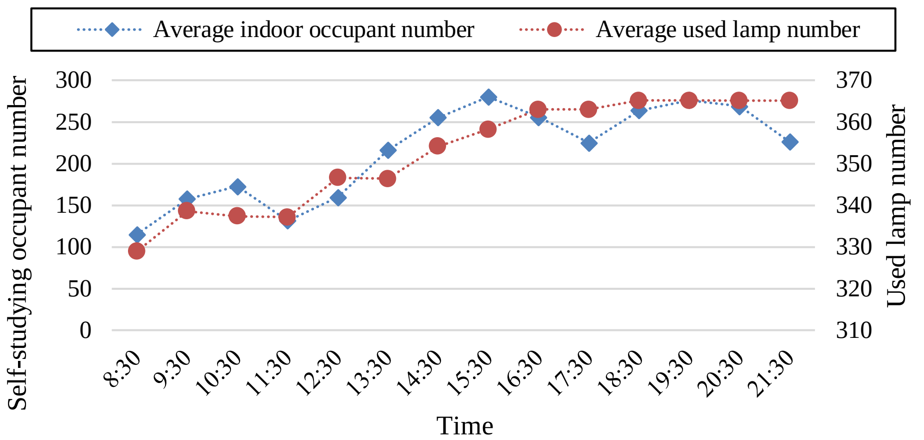


Figure 12. Time-varying used lamp number corresponding to self-studying occupant number.

An increasing tendency to reach the maximum is illustrated in Figure 12. In the morning period, the number of used lamps increases before 9:30 and then stays at a certain value until 11:30. The number of used lamps is not decreased with indoor occupants during lunch time, indicating that the lamps are not turned off by leaving occupants. The number of used lamps increases again when occupants go back to the classroom in the afternoon and is kept as another certain value. The value is higher than the value in the morning period, which is generally the maximum value. The increasing step reveals the lamps control habit of indoor occupants turning on actively and tuning off passively.

(2) Office building

Similar regularities can be seen from the investigation data of offices. Guests coming to the office building would not change the usage state of lamps. The key to lighting control is the workers in offices. The detailed number of lamps in use can be counted in an on-site survey. In order to quantify the relationship between the used lamps and indoor occupants, all the measured data of hourly used lamp and indoor occupant number are correspondingly shown in Figure 13.

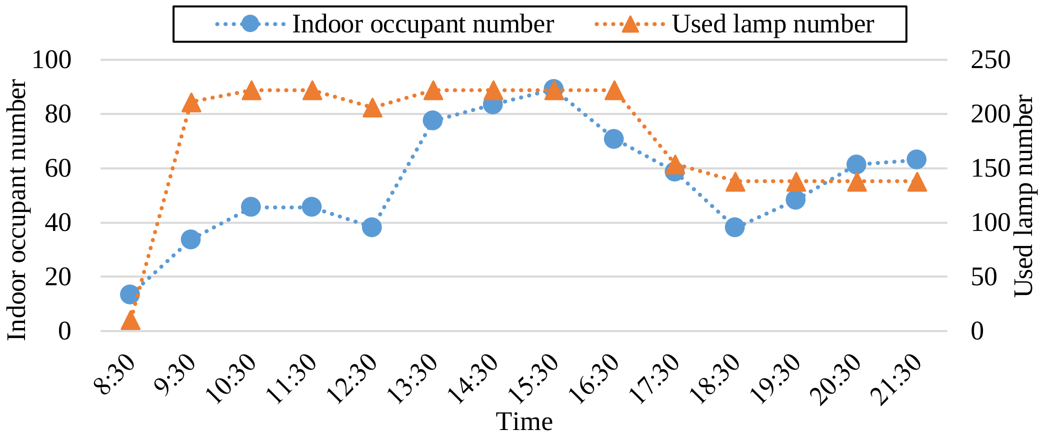


Figure 13. Time-varying used lamp number corresponding to indoor worker number in the office building.

Phase steps are clearly shown in Figures 12 and 13. The division of phases was the indoor occupant number. So, the control pattern of lighting can be described as "0-p-1" model. The detailed relationships of the teaching building and the office building are Equations (13) and (14), respectively.

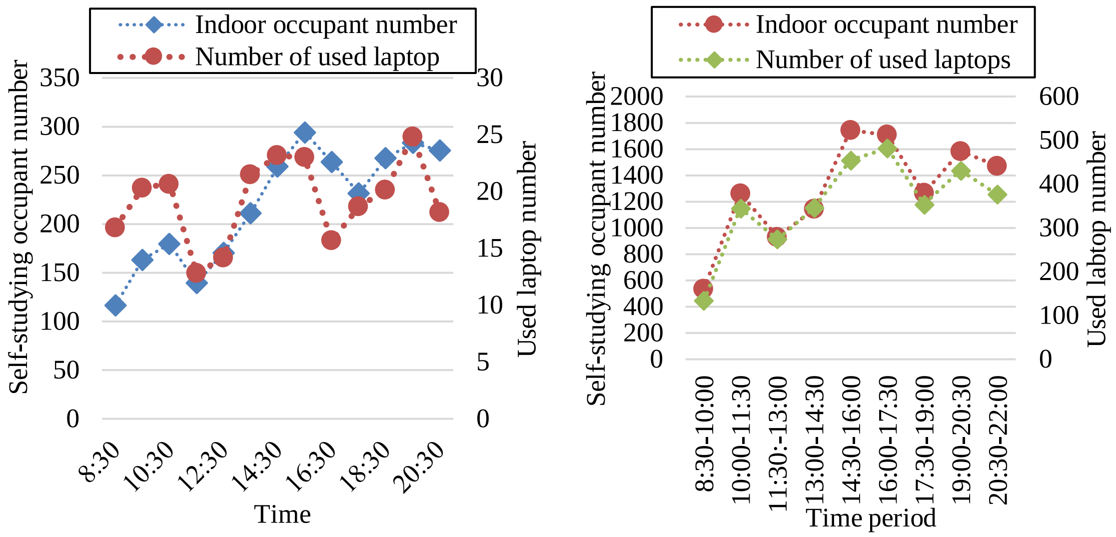
$$
\begin{aligned}
n_{lig.,cls.} &= \begin{cases} 0 & n_{se,cls.\tau} = 0 \\ g_{lig.} \cdot n_{se,cls.\tau}{}^{h_{lig.}} + 16 \times n_{cls} & 0 < n_{se,cls.\tau} < n_{\mathrm{lim.},lig.,cls.} \\ 700 \times (1 \pm 10\%) & n_{se,cls.\tau} \geq n_{\mathrm{lim.},lig.,cls.} \end{cases} \\
&= \begin{cases} 0 & n_{se,cls.\tau} = 0 \\ 241.25 n_{se,cls.\tau}{}^{0.21} + 16 \times n_{cls} & 0 < n_{se,cls.\tau} < 240 \quad (R^2 = 0.9143) \\ 700 \times (1 \pm 10\%) & n_{se,cls.\tau} \geq 240 \end{cases}
\end{aligned} \tag{14}
$$

$$
\begin{aligned}
n_{lig.,off.} &= \begin{cases} 0 & 0 < n_{occ,off.} \leq 3 \\ a_{lig.,off.} n_{occ,off.}{}^{b_{lig.,off.}} + 10 & 3 < n_{occ,off.} < 50 \\ 200 \times (1 \pm 10\%) & n_{occ,off.} \geq 50 \end{cases} \\
&= \begin{cases} 0 & 0 < n_{occ,off.} \leq 3 \\ 3.56 n_{occ,off.}{}^{1.03} + 10 & 3 < n_{occ,off.} < 50 (R^2 = 0.9014) \\ 200 \times (1 \pm 10\%) & n_{occ,off.} \geq 50 \end{cases}
\end{aligned} \tag{15}
$$

Because the lamps installed in the library are unified switched on or off by an automatic controller, no relationship was shown with indoor occupants.

4.2.2. Relationship of Equipment in Use with Indoor Occupants

The time-varying laptop number corresponding with self-studying occupants are shown in Figure 14.



(**a**) (**b**)

Figure 14. Time-varying used laptop number corresponding to self-studying occupant number. (**a**) Teaching building; (**b**) Library.

About 15% and 30% of occupants use laptops in the teaching building and the library, respectively, as illustrated in Figure 14. The number of laptops in use is generally synchronous changing with indoor occupant number. So, the relationship between indoor occupants and laptops in self-studying classrooms is linear.

As for other equipment installed in buildings, the research results in Ref. [40] were adopted, and the heat release of other equipment was considered as 10% additional to the computers and laptops. Based on the above analysis, the relationship between the number of pieces of equipment in use and indoor occupants is listed in Table 7.

Table 7. Description of the relationship between equipment and indoor occupants of case buildings.

Building	Equipment Type	Description
Teaching building	Computers Laptops Others	$n_{com.,cls.} = n_{inc}$ $n_{lap.,cls.} = 0.15 \times (n_{cls} - n_{inc})$ $n_{oth.,cls.} = 0$
Office building	Computers Laptops Others	$n_{com.,off.} = n_{ad,off.} + 0.95 n_{sc,off.}$ $n_{lap.,off.} = 0.05 n_{sc,off.}$ $n_{oth.,lib.} = n_{pr.,lib.} + n_{dr.,lib.} + n_{shr.,lib.}$
Library	Computers Laptops Others	$n_{com.,lib.} = 22$ $n_{lap.,lib.} = 0.3 \times n_{se,lib.\tau}$ $n_{oth.,lib.} = n_{TV,lib.}$

As listed in Table 7, the equipment installed in buildings is divided into three types, namely, computers, laptops, and other. The in-use number can be linearly described by the indoor occupant number.

4.3. Quantification of Representative Interior Load

4.3.1. Maximum Interior Load Density

The design interior load should be the maximum data considering all interior load disturbances. Based on the definition of *representative interior load*, the basic of the interior load is the indoor occupant density. In this section, the modified design occupant density is discussed, and the representative interior load for per occupant is proposed for the case buildings.

(1) Indoor occupant density

Based on the analysis in Section 4.1, the indoor occupant numbers of case buildings during holidays and general used days are different and should be considered separately.

For the teaching building, the measured maximum indoor occupant number was 600 during the general used period. The present time was 10:30–12:00 in the morning, namely, the 3rd and 4th class. The maximum data of the holidays was about 380 presented at 15:30 in the afternoon. So, the design indoor occupant densities during general used period and holidays are 0.1 and 0.06 person/m^2 correspondingly. The original design occupant density is 0.5 person/m^2. The occupant density of in-class rooms is about 0.52 person/m^2, which is 5 times higher than the average occupant density of the whole building. This is because of the function design of the teaching building. Teaching buildings should satisfy the demand for taking classes and self-studying at the same time. The probability of in-class for a class room was set at 50% as the maximum in the case teaching building. In addition, the actual occupant number of in-class rooms is lower than the design value. So, the actual occupied rate is much lower than the original design data.

The maximum indoor occupant numbers of the office building were 91 and 108 during the holidays and the general used period, respectively. The present time is also different. During holidays, the indoor occupant number at 15:30 in the afternoon is much more than that in the morning and evening. However, in general used days, the guests in some days might be more than other days and often occur in the morning. Hence, the maximum indoor occupant number might exist in the morning. For workers in the office building, the maximum occupant number presented is in the afternoon, around the on-duty time of 14:30–15:30.

In the library, the maximum indoor occupant number of 2196 showed at 16:30 and 20:30 during the general used period. The maximum data during holidays, which is 24.81% smaller than the above data, occurred at around 10:30 and 16:30 during holidays.

Based on the above analysis, the maximum occupant number of the case buildings generally occurred in the afternoon of general used period. The measured maximum indoor occupant density of the case building was summarized and compared with original design data in Table 8.

Table 8. Modified design indoor occupant density.

Case Building	Maximum Indoor Occupant Density (People/m^2)			
	Measured Data	Present Time	Original Design Data	Correction Factor of Holidays
Teaching building	0.1	11:30	0.5	0.61
Office building	0.04	10:30	0.25	0.84
Library	0.05	16:30, 20:30	0.5	0.76

As listed in Table 8, the modified design index of indoor occupant density was 80–90% smaller than the original design data. In addition, the design data should be different for holidays and general used period. Correction factors of holidays among 0.6–0.85 should be considered during the design of university buildings.

(2) Representative interior cooling load

Based on the relationships between other interior load disturbances and indoor occupant number analyzed in Section 4.2, the maximum used lamp number and computer/laptop number can be calculated for case buildings.

The heat release of appliances is transformed from electric power. For lamps, the rated power can be considered as the amount of heat release. However, for computers and laptops, the actual input power is much lower than the rated power. The distribution of input power various with the usage intensity. The Markov-Monte Carlo method of calculating the input power of computers in

Ref. [40] was adopted. The time-varying input power was measured for computers and laptops used in case buildings. The calculated steady input power of computers is listed in Table 9.

Table 9. Input power distribution of laptops and computers.

Computer Types	Average Rated Power (W)	Steady Input Power (W)	Sate Probability (%)			
			Standby	Low	Medium	High
Administration offices						
Computer	300	105.94	0.09	4.85	84.77	10.29
Scientific research offices						
Computer	300	96.13	16.67	34.85	24.24	24.24
Laptops	120	40.35	19.89	22.17	32.82	25.12
Thin & light laptops	60	15.73	15.36	54.37	17.96	12.31
Teaching building /Library						
Laptops	120	34.79	15.25	35.32	42.46	6.97
Thin & light laptops	60	13.79	25.19	42.51	30.77	1.53
Ratio of state input power to rated power			0.05	0.20	0.40	0.60

The main activity of occupants in the case buildings is sit and walk slightly. The heat release was considered as 70 W/person [20].

Based on the above analysis, the heat release per occupant can be calculated. So, the representative interior loads per occupant are 196.43, 329.94, and 402.58 W/person, respectively, in the teaching building, the office building, and the library.

4.3.2. Time-Varying Occupant Oriented Representative Interior Load

The time-varying indoor occupant number of the case buildings is described as Equations (10)–(12). The results of the undetermined coefficients through data fitting are listed in Table 10.

Table 10. Undetermined coefficients of data fitting results of indoor occupant number.

Case Building	Occupants Type	a_{occ}	b_{occ}	c_{occ}	Time Period	R^2
Teaching building	Self-studying occupants during holidays	−10.70	100.78	−76.61	7:30–12:30	0.9847
		−10.24	86.75	56.38	13:30–17:30	0.9115
		−17.08	111.12	83.89	18:30–22:30	0.9358
	Self-studying occupants during general used period	−43.79	324.65	−261.71	7:30–12:30	0.9871
		−13.21	107.92	−9.35	13:30–17:30	0.9434
		−71.20	410.30	−255.36	18:30–22:30	0.9788
Office building	Scientific research workers during holidays	−10.94	69.29	−72.87	7:30–12:30	0.9246
		−2.83	24.99	−1.90	13:30–17:30	0.9035
		−3.57	17.83	22.06	18:30–22:30	0.9276
	Administration workers during general used period	−3.75	20.00	8.75	7:30–12:30	/
		−4.00	26.00	−10.00	13:30–17:30	/
	Scientific research workers during general used period	−3.01	29.14	−26.31	7:30–12:30	0.9523
		−5.21	39.90	9.82	13:30–17:30	0.9146
		−6.94	41.93	−0.73	18:30–22:30	0.9552
Library	Self-studying occupants during holidays	−125.30	1065.50	−1072.90	7:30–12:30	0.9215
		−51.94	559.49	−233.54	13:30–17:30	0.8994
		−164.86	804.66	161.61	18:30–22:30	0.9503
	Self-studying occupants during general used period	−127.41	1067.10	−974.63	7:30–12:30	0.9637
		−95.19	808.18	125.47	13:30–17:30	0.9778
		−342.88	1843.00	487.31	18:30–22:30	0.9107

Based on the average time-varying data of indoor occupant number and the representative interior load per occupant, the time-varying interior cooling load can be calculated. The results are shown in Figure 15.

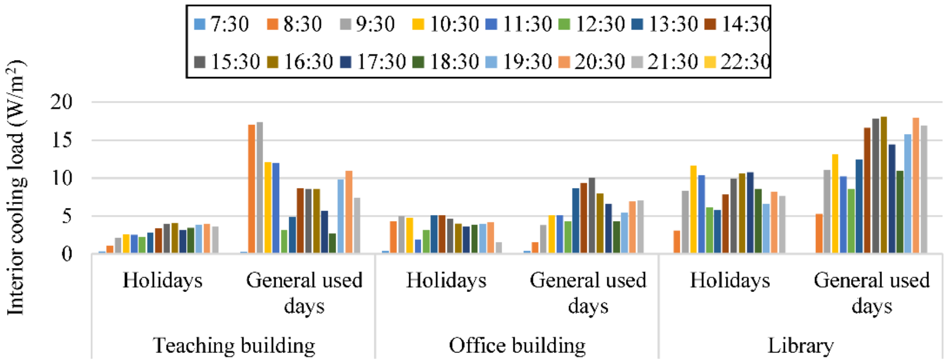
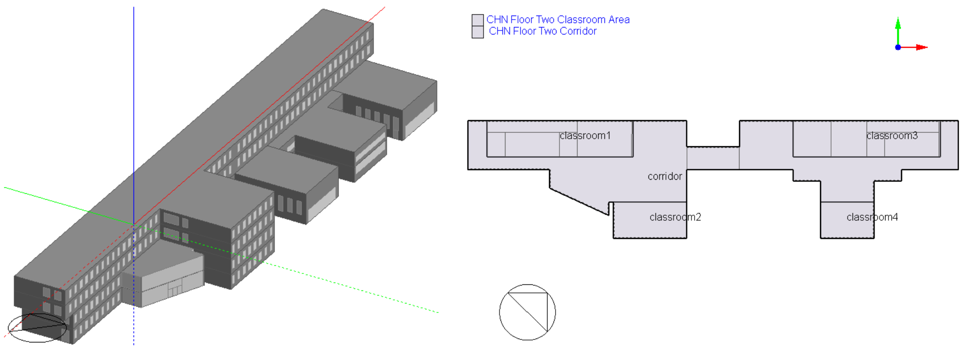


Figure 15. Interior cooling load calculation results of case buildings.

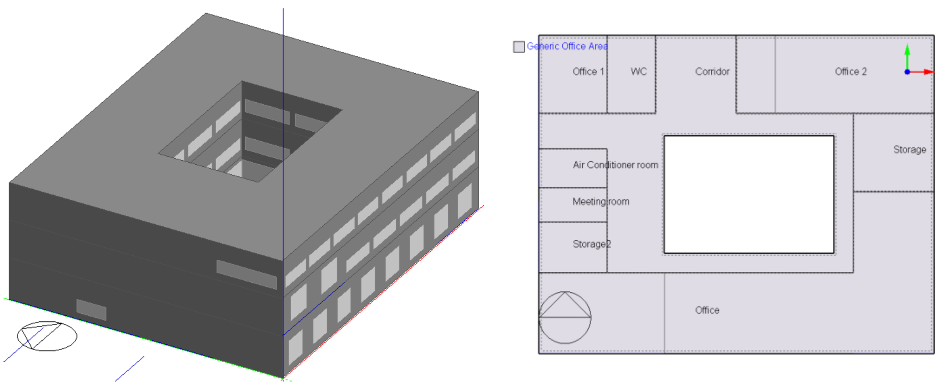
4.4. Modified Cooling Load Results Validation and Discussion

This section illustrated the validation and assurance rate of the modified design interior cooling load. Based on the building information in Section 2.4.1, the simulation models of the case buildings based on DesignBuilder tool are shown in Figures 16–18, respectively.



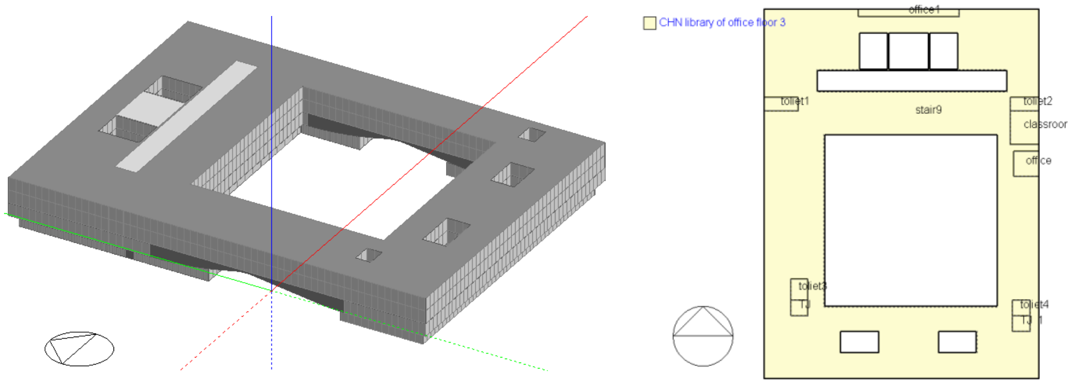
(**a**) (**b**)

Figure 16. Building cooling load simulation model based on DesignBuilder of the teaching building. (**a**) External view and (**b**) interior division of standard floor.



(**a**) (**b**)

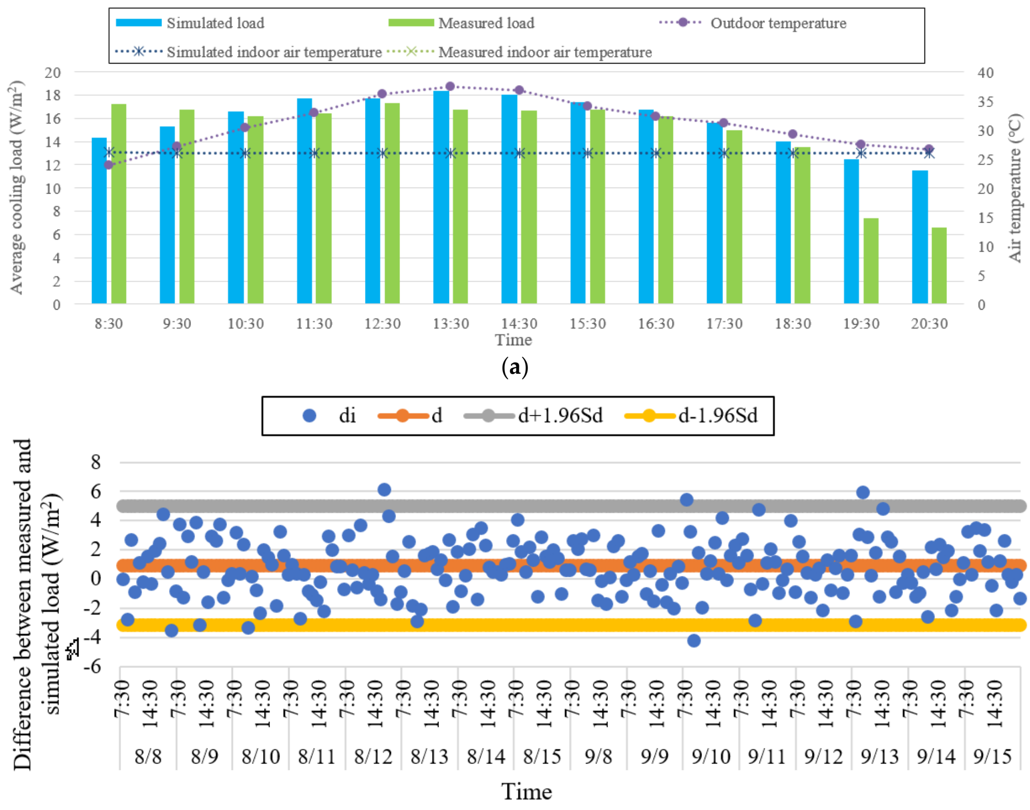
Figure 17. Building cooling load simulation model based on DesignBuilder of the office building. (**a**) External view and (**b**) interior division of standard floor.



(a) (b)

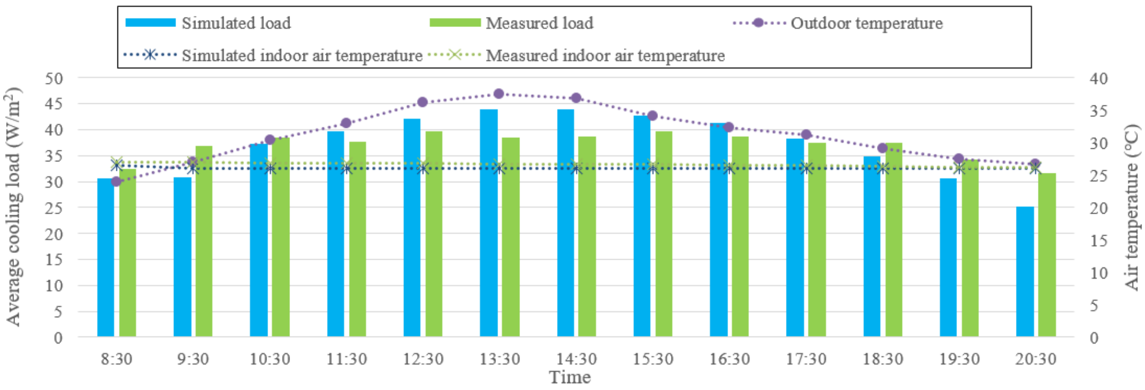
Figure 18. Building cooling load simulation model based on DesignBuilder of the library. (**a**) External view and (**b**) interior division of standard floor.

The time-varying interior loads for the three buildings were input in the form of schedule. The above-calculated time series of occupant-oriented representative interior cooling load was set for main functional building, for example, classrooms for the teaching building and offices for the office building. The occupancy rate and appliance density were set as 0 for other spaces, such as washing room, corridor, etc. The fresh air was controlled by minimum requirement, namely, 8 L/(s·person) for the teaching building and library and 10 L/(s·person) for the office building [20]. The comparison of the simulated results and measured cooling loadis shown in Figures 19–21, respectively.

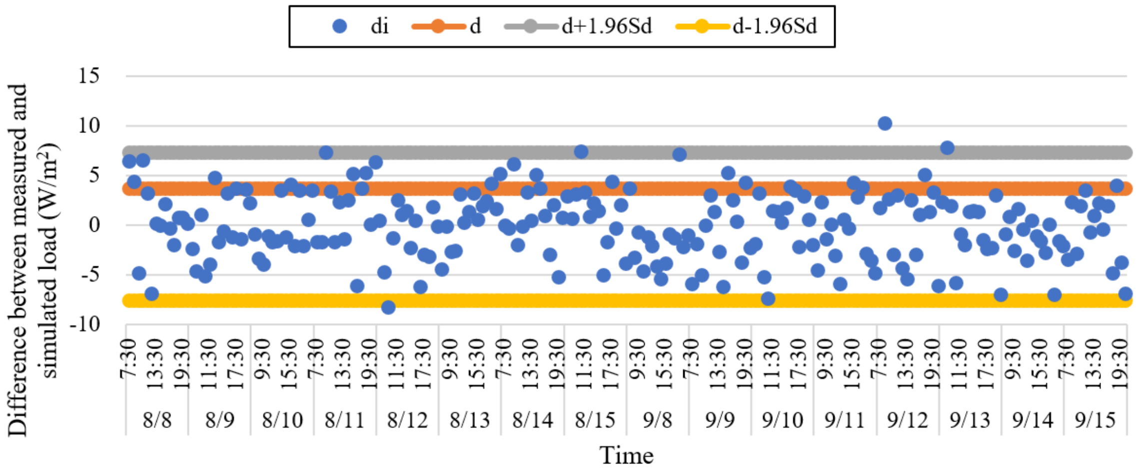


(b)

Figure 19. Comparison of simulated and actual building cooling loads of the teaching building. (**a**) Time-varying loads and (**b**) consistency validation.

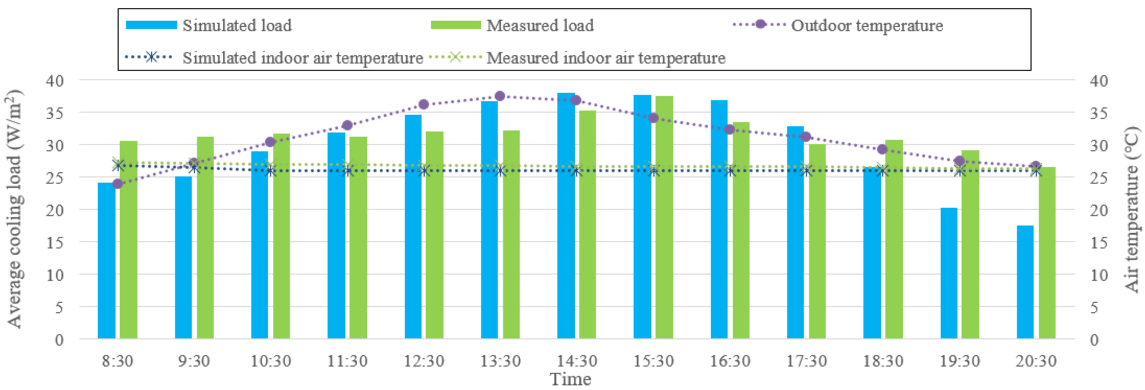


(**a**)



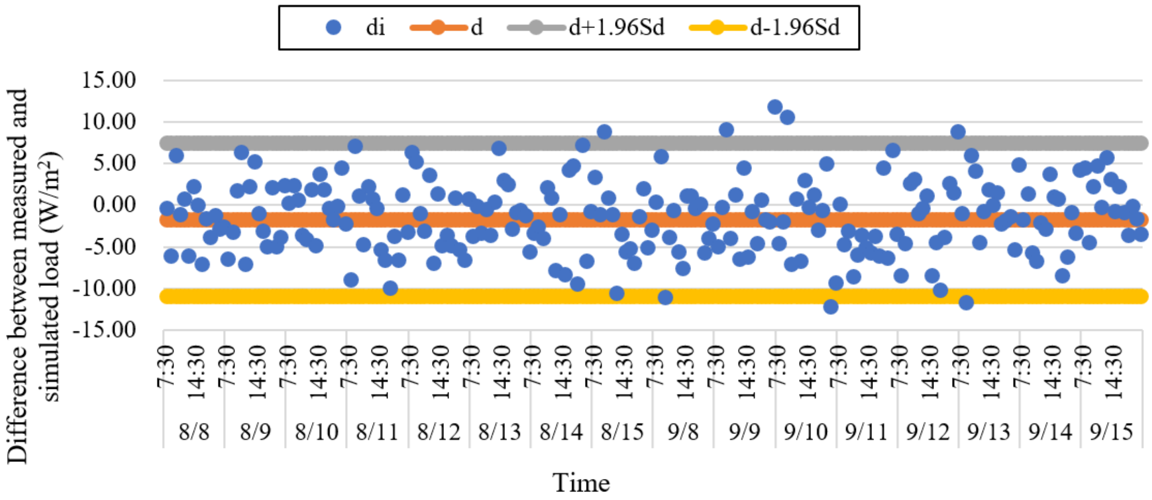
(**b**)

Figure 20. Comparison of simulated and actual building cooling loads of the office building. (**a**) Time-varying loads and (**b**) consistency validation.



(**a**)

Figure 21. *Cont.*



(**b**)

Figure 21. Comparison of simulated and actual building cooling loads of the library. (**a**) Time-varying loads and (**b**) consistency validation.

As shown in Figures 19–21a, the simulated cooling data has a good consistency with measured data. The average error rates are 7.37%, 1.70%, and 9.54%, respectively, for the teaching building, the office building, and the library. This means the accuracy satisfies the requirement of more than 90%. The errors lie in the following aspects. Firstly, the indoor air temperature changes with time at practice. However, the design indoor air temperature should be a certain value. Secondly, the sun-shading is not considered during simulating, which may cause relatively high error in buildings with large windows. So, the error rate of the library is higher than other buildings. Comparing the error rates of case buildings, it can be inferred that the proposed method is more accurate for buildings with relatively fixed usage habits. In the office building, the workers are permanent over a long time period, at least one or two years. So, the variations in occupant behaviors and requirements are small. However, the occupants change every day, even every hour. Occupant behavior might be extremely different when using lamps and equipment. Though the cluster effect can be summarized, errors are inevitable. Validation is necessary to estimate the inevitability. Figures 19–21b, show the consistency check results. Only 5,4 and 7 out of 220 sets of data are out of range for the teaching building, the office building, and the library, respectively. This indicates that the simulated cooling loads are very close, at least 92.73%, to the actual cooling load when taking the indoor occupants and the occupant-oriented representative cooling load into account.

The design cooling load should be the maximum hourly cooling load under design conditions. Based on the commonly used design cooling load calculation method of cooling load coefficient method in Ref. [19,20], the modified cooling loads are listed in Table 11. In order to compare the modified cooling load indexes with the recommended values in relative standards [20], the cooling load intensity (CLI, W/m^2) was calculated by

$$CLI = \frac{\max(CL_\tau)}{A} \tag{16}$$

Based on the percentage of interior load in total design cooling load, the recommended interior cooling load can be calculated and is listed in Table 11. The over-estimating rates of interior cooling load on the basis of recommended data are at least more than 50%. In the teaching building, the over-estimating rate is even 5–7 times greater. In addition, the cooling capacity of installed WSHPs in the zone energy station is about 1.61 times higher than modified cooling load, indicating the design problems of oversizing chillers.

Table 11. Modified design cooling load of case buildings.

	Exterior	Fresh Air	Interior	Total
Case building	Teaching building			
Modified cooling load (W/m^2)	13.49	3.32	17.36	34.17
Percentage (%)	39.48	9.72	50.80	100
Recommended cooling load (W/m^2)	63.17–94.75	15.55–23.33	81.28–121.92	160–240
Over-estimating rate (times)	4.68–7.03			
Case building	Office building			
Modified cooling load (W/m^2)	32.61	15.61	9.96	58.18
Percentage (%)	56.05	26.83	17.12	100
Recommended cooling load (W/m^2)	50.45–67.26	24.15–32.20	15.41–20.55	90–120
Over-estimating rate (times)	1.55–2.06			
Case building	Library			
Modified cooling load (W/m^2)	37.50	4.50	18.12	60.12
Percentage (%)	62.37	7.49	30.14	100
Recommended cooling load (W/m^2)	62.37–99.79	7.49–11.98	30.14–48.22	100–160
Over-estimating rate (times)	1.66–2.66			

In this research, the teaching building, office building, and library were taken as examples to show the application of the proposed method. Actually, the proposed occupant-oriented representative interior load calculation method is suitable for all buildings in which occupants are able to control the energy consumption appliances. The method provides a solution to the significant problem of building usage conditions that should be considered not only in building load design but also in energy system management. For the buildings with fixed control patterns of appliances, such as canteens, the occupant-oriented concept of this paper is meaningful to optimize the management strategies of energy systems.

5. Conclusions

An occupant-oriented interior cooling load calculation method was proposed in this paper to improve the accuracy of the building interior cooling load design. The nature of the interior cooling load disturbances was explored. The definition of *representative interior load* was proposed, quantified, and verified by the application of the building cooling load calculation. Typical university buildings were taken as special cases to obtain building usage data, including the time-varying number of indoor occupants, lamps, and equipment in use. The survey covered both generally used days and holidays, weekdays, and weekends, which is sufficient to support the usage analysis of university buildings. The following conclusions can be drawn.

(1) The proposed *occupant-oriented representative interior load* is a combination of all interior disturbances. Occupants are the core of interior cooling loads. Occupants should be categorized based on their equipment usage. Through quantitative analysis, it was observed that the maximum representative interior loads were 196.43, 329.94, and 402.58 W/person, respectively, for the case buildings, indicating the different natures of occupants in various building types.

(2) The time-varying indoor occupant number followed a trimodal distribution of university buildings, which could be described by quadratic polynomials with the time interval of 1 h. The used lamps and equipment were in exponential and linear relationships with the indoor occupants, respectively. Considering the maximum indoor occupant number, the design interior cooling load of the case buildings was modified as 17.36, 9.96, and 18.12 W/m^2, respectively, counting for 50.80%, 17.12%, and 30.14% of the total cooling loads. The over-estimating rate of the interior cooling loads resulted in the oversized chillers, which were proved to be more than 50%.

(3) The proposed representative interior load calculation method can easily be applied in the building load simulation by inputting the time-varying schedules. A consistency rate of more than 90% has been achieved in the case buildings. The feasibility and accuracy can be proved to be meaningful with regard to the proposed occupant-oriented interior cooling load design method.

6. Patents

A prediction method of office energy consumption (CN2014105880898).

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Nomenclature

CL	Cooling load (W)
q	Heat release (W)
E	Input power (W)
n	number
C	Cooling load coefficient
A	Building floor area (m^2)
f	Function
d	Mean value of the difference between two groups of data
a, b, c	Undetermined coefficients of quadratic polynomials
g, h	Undetermined coefficients of exponential relationships
Greek letters	
λ	Usage rate (%)
φ	Clustering coefficient to adjust heat gain based on normal percentage of men, women, and children
Subscripts	
i	Interior load disturbance types
ex	Exterior cooling load
f	Fresh air cooling load
in	Interior cooling load
re	Representative interior load
occ	Occupant
$lig.$	Lighting
$eqp.$	Equipment
$eqpi$	Equipment type i
$lap.$	Laptops
$com.$	Computers
$pr.$	Printers
$dr.$	Water dispensers
$shr.$	Shredders
k	Number of data sets
j	Data set j
τ	Time
m	Morning period, 7:30–12:30

a	Afternoon period, 13:30–17:30
n	Night period, 18:30–22:30
$cls.$	Classrooms in the teaching building
se	Self-studying
inc	In-class
$off.$	Offices in the office building
$ad.$	Administration workers
$sc.$	Scientific research workers
$gu.$	Guests
$lib.$	The library
$br.$	Borrowing and returning books occupants
$ma.$	Management workers
lim.	Limit point of occupant number
$oth.$	Others

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