Temporal and Spatial Predictability of Occupants’ Presences in a Library Building

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Abstract

Although it has been widely acknowledged that occupants play a critical role in building energy consumption, the characteristics of the occupants’ presences and actions are not accurately represented in building simulation tools.

In this study, the authors aim to identify the temporal and spatial difference in the characteristics of the occupants’ presences in a library building located in South Korea. The data of each individual entering and leaving rooms in the building were recorded for weeks from 15 to 31 January by Radio-Frequency Identification (RFID) tags. Based on the data, the periodicity and predictability of the occupants’ presences were investigated in terms of (1) spatial variation (individual room vs. entire floor vs. entire building), and (2) temporal variation (5 minutes vs. 30 minutes vs. 1 hour sampling times). The periodicity and predictability of the occupants’ presences were quantified using a Normalized Cumulative Periodogram (NCP).

The occupants’ presences in an individual room were less periodic or less predictable than those in the entire building. The predictability of the occupants’ presences was influenced by the sampling time. The greater the sampling time (5 minutes vs. 1 hour), the better predictable the occupants’ presences were. In other words, it is much easier to predict the aggregated number of occupants over the entire building with a longer sampling time (e.g. a couple of hours) than to predict the number of people in individual rooms with a shorter sampling time (e.g. 10 minutes). These findings could be further applied to an energy simulation study of the building and its relevance to energy prediction will be studied.

1. Introduction

Recently, the study of occupant behavior has attracted significant attention from the Building Performance Simulation (BPS) community (IBPSA, 2011-2015). It has been widely acknowledged that the occupant is one of the major factors contributing to the performance gap (IEA Annex 66, 2016). In this regard, a number of occupant behavior models have been developed to describe the occupants’ presences (Page et al., 2008; Feng et al., 2015). One of the most popular stochastic approaches is a Markov chain model. The model is based on a large amount of observed data and addresses a statistical relationship between occupants’ presences and actions, and other environmental factors. In addition, a sophisticated Markov chain model adopts an agent-based modeling approach to take into account human sensation, perception, cognition, and psychomotor responses (Yan et al., 2015).

Another approach for the prediction of the occupants’ presences, so-called ‘random walk’ was recently published (Ahn and Park, 2016). It is based on the belief that the predictability of the occupants’ presences can vary, depending on the type of buildings (process-driven buildings such as schools, residences vs. ‘random walk’ buildings where the occupants’ presences are not predictable).

It is still unsolved and untouched whether such predictability of the occupants’ presences varies spatially and temporally. In this paper, the authors aim to investigate the periodicity and predictability of the occupants’ presences in terms of spatial and temporal variation. The number of people entering and leaving rooms in a library building recorded for two weeks was used. Then, for the quantification of the periodicity and predictability, the Normalized Cumulative Periodogram (NCP) was used.

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2. Random Walk

A random walk is a mathematical formalization consisting of a succession of random steps. The term "random walk", first introduced by Pearson (1905), has been used in many fields (e.g. ecology, economics, psychology, etc.) to explain observed time-series behavior. Fig. 1 shows an example of twenty random walks in one dimension, showing the current position on the y-axis over time (x axis) (Ahn and Park, 2016).

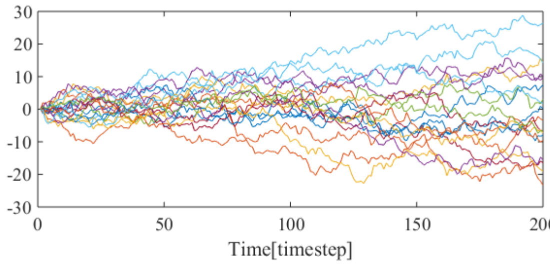


Fig. 1 – Example of twenty random walks

The mathematical form of random walk for time-series data is as follows (Gelb, 1974):

$$x_{k+1} = x_k + w_k \quad (1)$$

where x_k is the state of the k^{th} time-step, x_{k+1} is the state of the $(k+1)^{th}$ time-step, and w_k is the difference between x_k and x_{k+1}, meaning the difference in the state over time.

The time series w_k can be characterized by a frequency analysis with Fourier transform. The Normalized Cumulative Periodogram (NCP) is a common method to identify the periodicity of a given time series in a frequency domain (Hipel and McLeod, 1994).

Fig. 2 shows the NCP of 1,000 random numbers (bold blue line) and dotted lines indicate 95 % confidence intervals. It can be said that w_k follows the random walk if it is drawn within a confidence interval (pink area) along with a straight line joining (0, 0) and (0.5, 1) in the NCP (Hipel and McLeod, 1994). More details on the random walk can be found in (Ahn and Park, 2016).

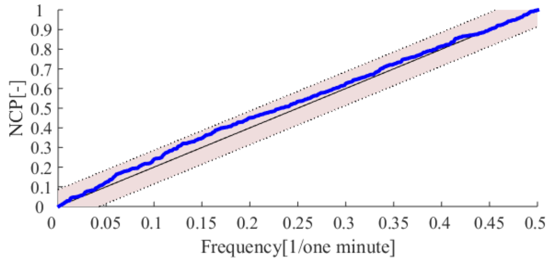


Fig. 2 – Example of NCP for 1,000 random numbers

3. Target Building

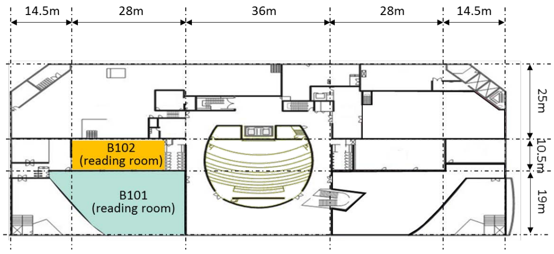
The target building is a library building of Sungkyunkwan University located in South Korea. The building has two underground floors and seven aboveground floors, and its total floor area is about 23,742 m^2. A circular seven-story high atrium is located at the center of the building (Fig. 3).

All library entrance gates are operated with an access management system that records each individual entering and leaving through the use of Radio-Frequency Identification (RFID) tags. In addition, six rooms (Room #: B101, B102, 101, 201, 301, 302) in the building are equipped with a RFID system that issues and records a seat number of each individual (Fig. 3). In this study, the authors used two weeks' data of the six rooms from 15 to 31 January (Table 1 and Fig. 3).

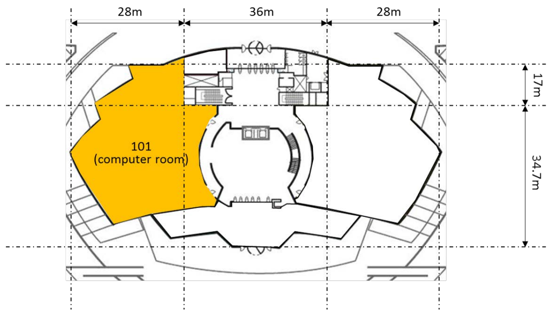
Table 1 – Selected six rooms

Room #	Use	Location	Area (m^2)	Max. # of people
B101	Reading Room	B1	560	84
B102	ReadingRoom	B1	265	67
101	Computer Room	1F	1,029	56
201	Media Room	2F	420	9
301	Reading Room	3F	863	9
302	Reading Room	3F	733	9
Total	-	-	3,870	234

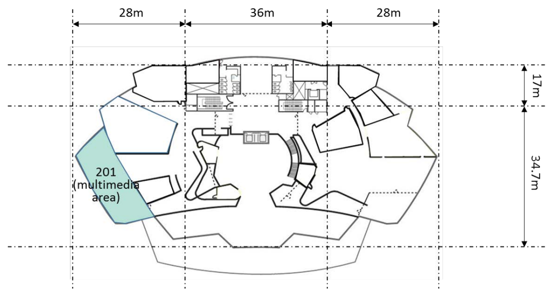
(a) Target building



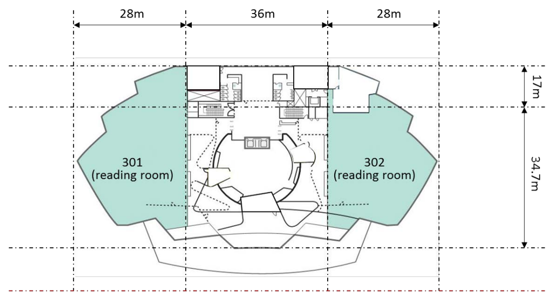
(b) B1 floor (1st underground floor)



(c) 1st floor (1F)



(d) 2nd floor (2F)



(e) 3rd floor (3F).

Fig. 3 – Floor plan of the target building

4. Results

To investigate the spatial characteristics of the occupants' presences, the authors categorized the six rooms into three levels: room level, floor level (B1 level: B101+B102, 1F: 101, 2F: 201, 3F: 301+302), and the entire building level. Fig. 4 shows the number of occupants based on the three levels.

Fig.s 5-10 show the NCP of the occupants' presences (x_k) and the variations in the occupants' presences (w_k).

The NCPs of w_k in Rooms #201, #301 and #302 ((Fig. 5 (h), (j), (l)) prove the random walk. The blue lines are located inside the confidence interval and are evenly distributed over the entire period. This means that w_k of Rooms #201, #301 and #302 are unpredictable (Fig. 5).

It is interesting that when the NCP of w_k is analyzed in the building level, w_k of the entire building becomes predictable (Fig. 6(f)). In other words, the variation in the occupant's presences for the small groups of people (accommodating only 9 people in Rooms #201, #301 and #302, Table 1) is unpredictable, while that of the entire building is predictable. It means that it would be difficult to predict the variation in the small group of occupants in a room, while it is possible to predict the aggregated number of people in the entire building.

In addition, the degree of randomness in w_k varies depending on the sampling time (Fig.s 5-6 vs. Fig.s 7-8 vs. Fig.s 9-10). As mentioned above, w_k in Rooms #201, #301 and #302 (Fig. 5 (h), (j), (l)) follows the random walk when the sampling time is 5 minutes. However, w_k in the same rooms (#201, #301, and #302) do not follow the random walk when the sampling time is 30 minutes (Fig. 7 (h), (j), (l)). It also applies when the sampling time is 1 hour (Fig. 9 (h), (j), (l)).

It means that it is difficult to predict the variation (w_k) in the occupants' presences with a short time interval (5 minutes), while it would be easier to predict w_k with long-enough sampling times (e.g. 30 minutes, 1 hour).

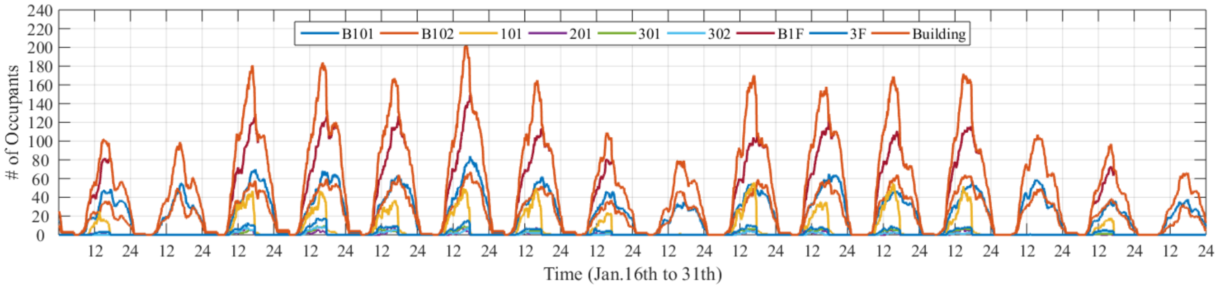


Fig. 4 – The number of occupants (sampling frequency: 5 minutes)

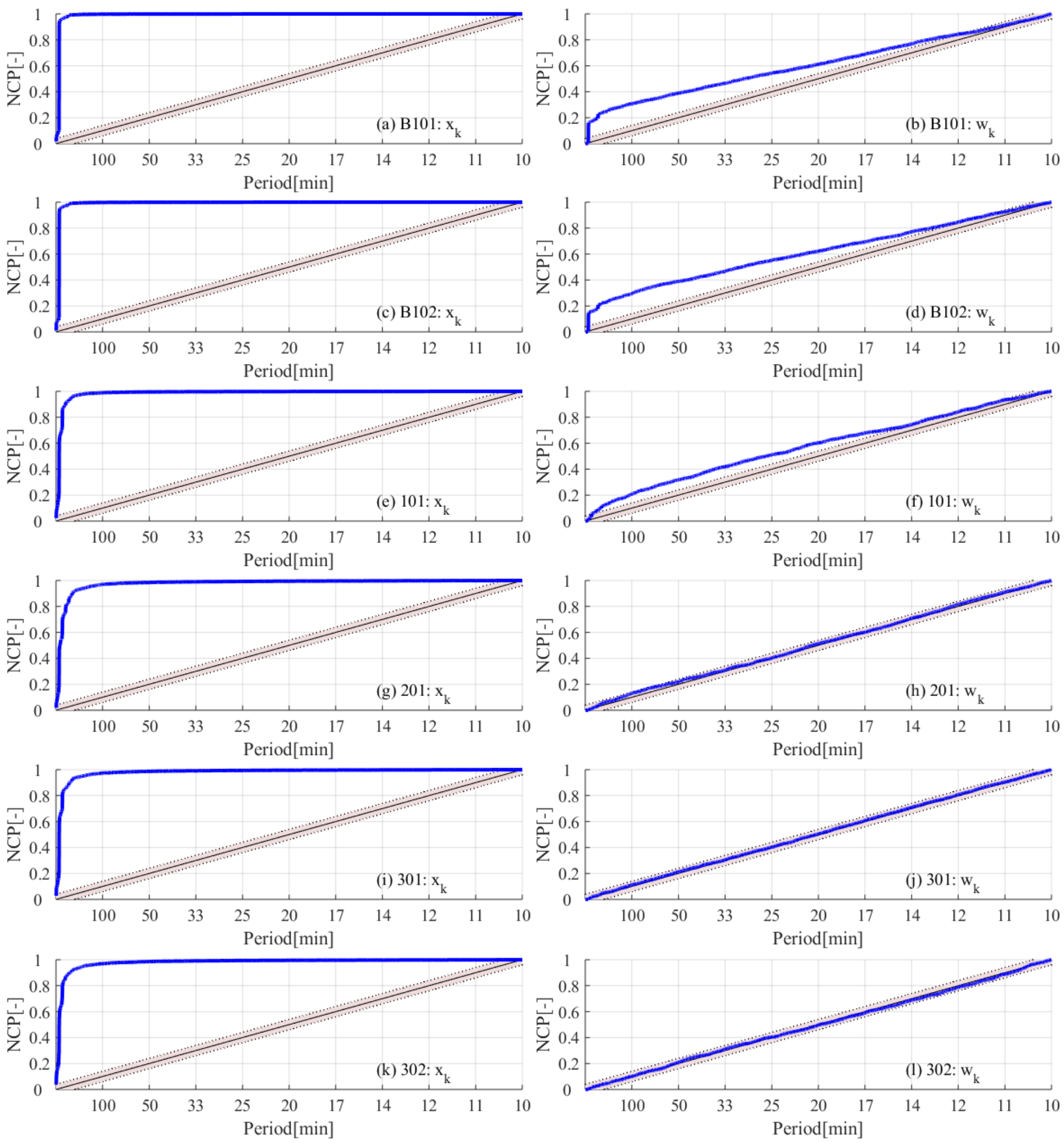


Fig. 5 –NCPs of individual room (sampling time: 5 minutes)

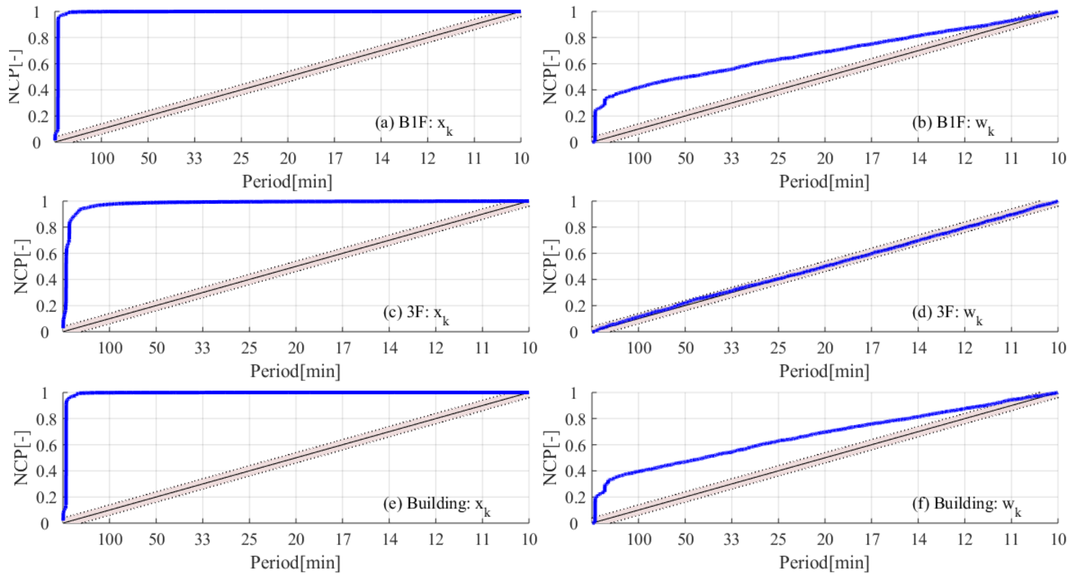


Fig. 6 – NCPs of floor and building level (sampling time: 5 minutes)

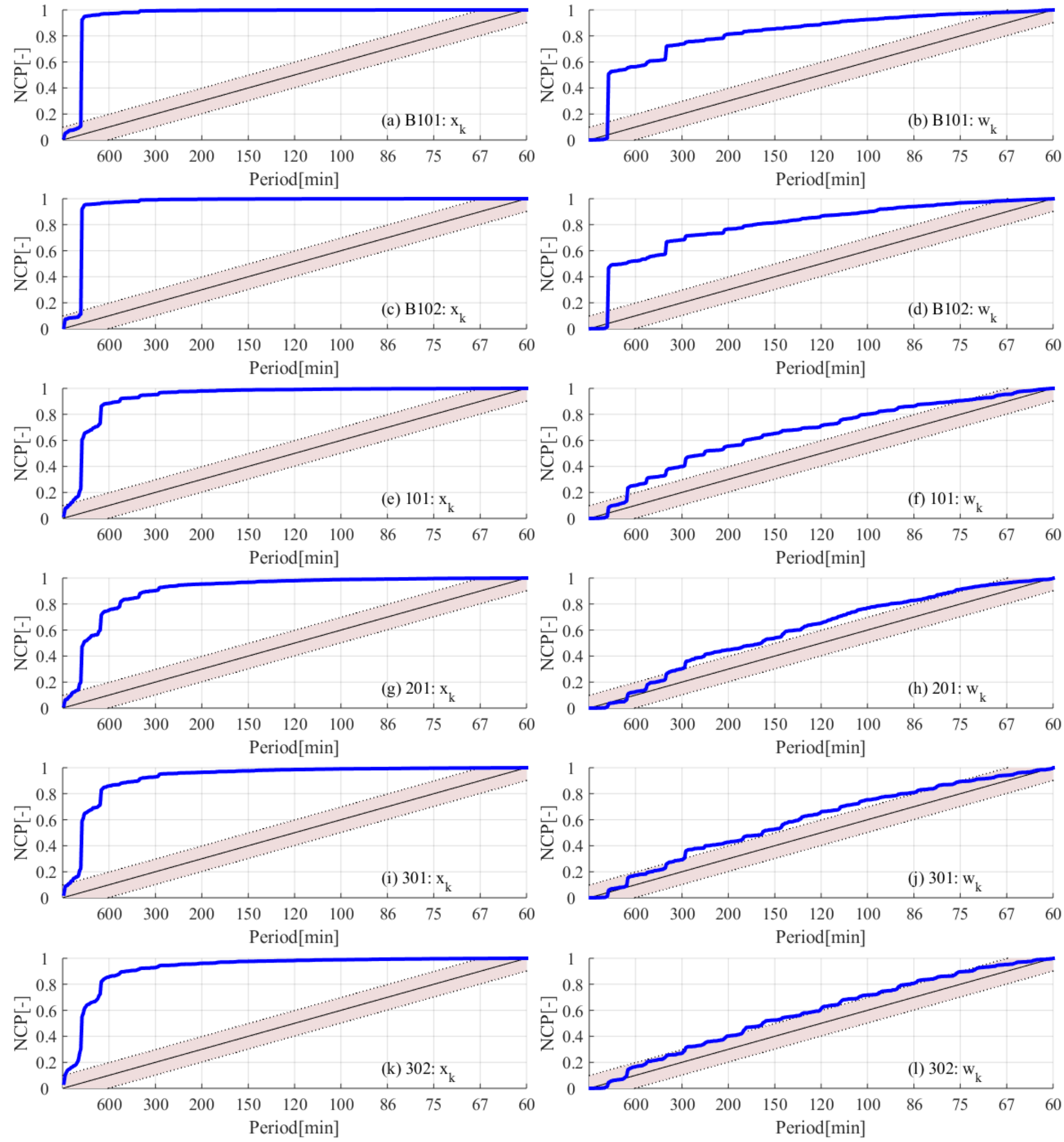


Fig. 7 – NCPs of individual room (sampling time: 30 minutes)

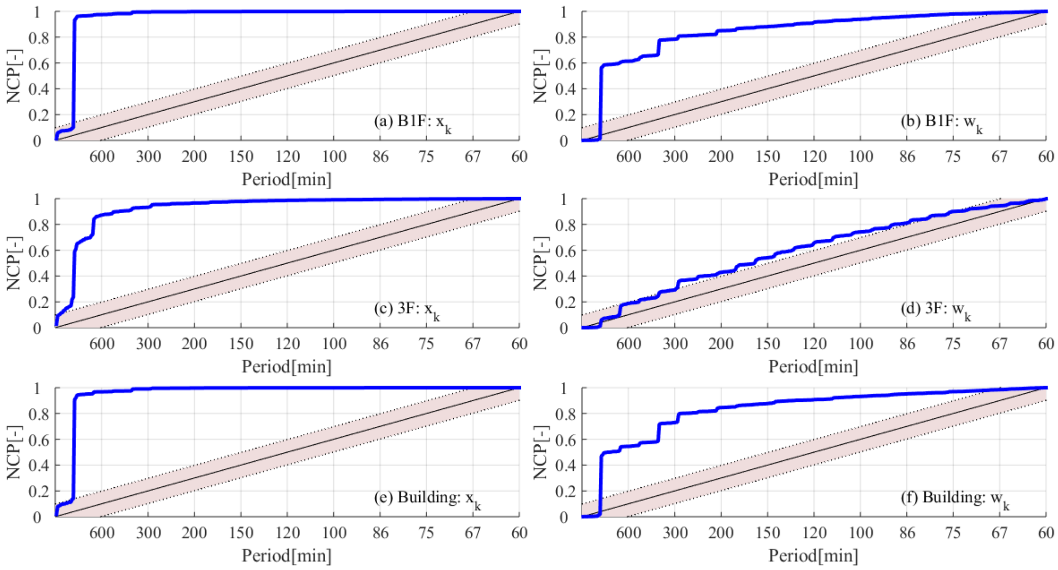


Fig. 8 – NCPs of floor and building level (sampling time: 30 minutes)

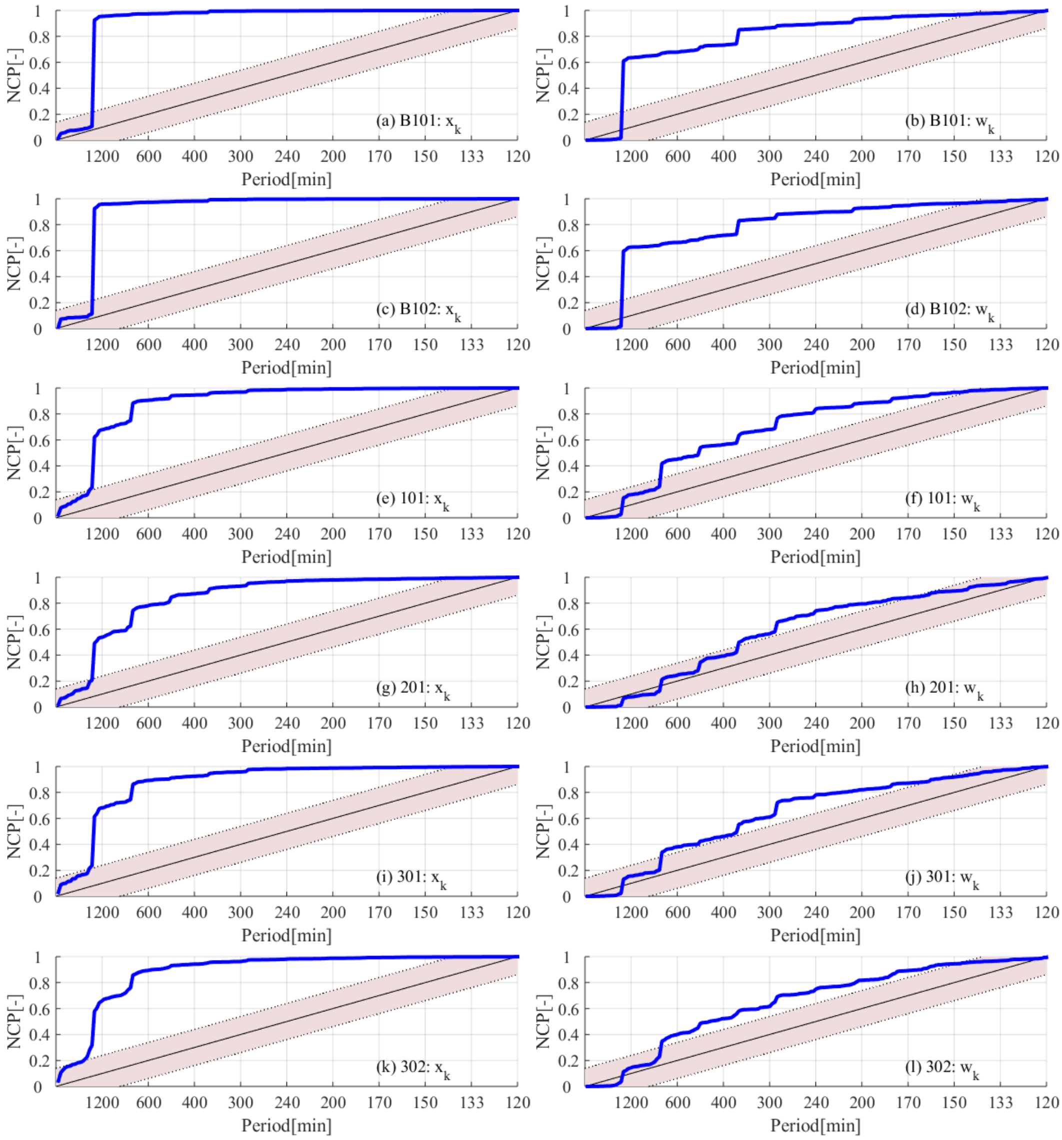


Fig. 9 – NCPs of individual room (sampling time: 1 hour)

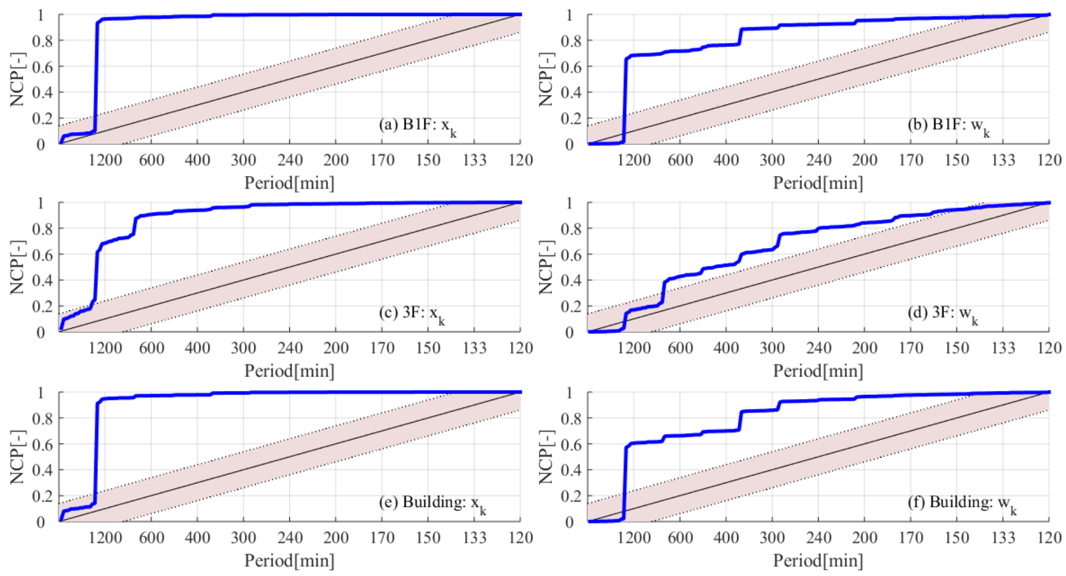


Fig. 10 – NCPs of floor and building level (sampling time: 1 hour).

5. Conclusion

The authors investigated the predictability of the occupants' presences in terms of the number of occupants (e.g. individual room level, floor level, building level) and in terms of the sampling times (e.g. 5 minutes, 30 minutes, 1 hour). This study was based on the monitored data for two weeks (from Jan 16 to Jan 31) at a library building in South Korea. The findings of this study are as follows:

- It is quite difficult to predict the variation (w_k) in the number of occupants of a small group, e.g. comprising 9 people. In contrast, the variation in the number of occupants of the entire building is predictable.
- The predictability of w_k depends on the sampling time. When the sampling time is as short as 5 minutes, w_k in a small group is unpredictable. When the sampling time becomes as long as or longer than 30 minutes, w_k in a small group is even predictable.

The aforementioned findings will be used for the uncertainty analysis of the energy prediction of the building in the near future. In addition, the quantification of the relation between the sampling time and the group size will be further investigated.

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