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ITERATIVE REASSIGNMENT ALGORITHM: LEVERAGING OCCUPANCY BASED HVAC CONTROL FOR IMPROVED ENERGY EFFICIENCY

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ABSTRACT

Building occupancy significantly impacts HVAC system energy consumption. Occupancy is stochastic in nature, and occupancy from different spaces could be heterogeneous, resulting in heterogeneous distributions of loads, therefore HVAC energy inefficiencies. This paper proposes a framework for conditionally redistributing loads by reassigning occupants at the building level for elevating the effects of occupancy based control, and simulates a real-world office building for validation. Predefined constraints are integrated, and an agglomerate hierarchical clustering-based reassignment algorithm is designed for iteratively assigning occupancy with zone adjacency, orientation, and HVAC layout being considered. Simulation results show that the integration of occupancy based control and occupant reassignment could save up to 9.6% of energy compared to simply applying occupancy based control (18.9% compared to the baseline control that is used in the building. The proposed framework helps reducing unnecessary loads and improves energy efficiency through better-informed decision making for occupancy based HVAC controls.

1 INTRODUCTION

With the ever-rising energy demands and diminishing supplies of nonrenewable energy resources, sustainability and energy conservation have become increasingly important topics. In the U.S., approximately 40% of the total energy consumption is attributed to buildings, with 45.8% consumed by commercial buildings (USDOE 2014). Commercial buildings are promising targets for increasing energy efficiency, considering their long lifespan, rapid increase of area, large amount of CO_2 emissions, high intensity of energy consumption per square foot, and lack of incentives for energy reduction, (USDOE 2014; ACEEE 2013). Since more than 40% of commercial building energy is used by HVAC (Heating, Ventilation, and Air Conditioning) systems to maintain comfortable and healthy indoor thermal environments, efficiency for HVAC systems should be given the priority (USDOE 2014). In general, there is a difference between *nominal demands*, amount of energy required to maintain the thermal conditions of spaces, and *actual demands*, amount of energy required to maintain the thermal conditions for occupants. It has been widely recognized that occupancy is one of the most important factors impacting actual demands for HVAC systems. There is great potential for energy efficiency if occupancy is considered in the operations of HVAC systems since one way of improving efficiency is to minimize the difference between actual demands and nominal demands (Kwok et al. 2011).

Load is a quantitative measure to describe demands. In office buildings, heat gain/loss resulting from conduction, radiation and infiltration through building envelopes, as well as from the heat produced by occupants, computers, and other equipment, are the loads for heating/cooling. Occupancy determines heating/cooling periods and desired thermal conditions (actual conditioning requirements), which differentiate actual demands (effective loads) from nominal demands (total loads). Occupancy usually has patterns but it is stochastic (contains random variations) in nature. It can be described from two perspectives: (1) Real time occupancy is occupancy status at each time point; it may vary as time passes and depicts the one-time occurrences of occupant presence/absence changes.; (2) Long term occupancy, also called personalized occupancy profile, indicates a typical-weekday/weekend presence probability as a function of time. An occupancy profile is for a specific space, representing the space's long-term habitual presence patterns (occupancy patterns) for the day of week. In addition, occupancy has variety, resulting in heterogeneous distributions of effective loads (creating varied requirements for heating/cooling) and therefore, resulting in unnecessary energy consumption. It has been demonstrated by previous research that zone level load redistribution by clustering and reassigning loads based on occupancy similarities, could significantly improve energy efficiency (Yang and Becerik-Gerber 2014a).

However, an HVAC system is a network consisting of more than one zone and there exist load transfer and balance among different zones, as well as heat gain and loss through a building's envelope. Since adjacent zones are commonly served by the same supply air and also have shared or similar boundary conditions (ASHRAE 2009), if they have similar occupancies and vacancies, they would have similar load distributions and therefore, the loads for the entire system could be reduced. In addition, redistributing relatively low effective loads to perimeters of a building and integrating occupancy time-dependence with orientation also have the potential to reduce the impacts of external loads. This paper proposes a framework to conditionally redistribute loads by reassigning occupants at the building level and presents results from a simulation of a real-world office building for validation. Predefined requirement constraints (e.g., room size) and capacity constraints (e.g., number or rooms within a zone) are integrated, and an agglomerate hierarchical clustering based algorithm is designed for iteratively assigning occupants with zone adjacency, orientation, and HVAC layout being considered.

This paper is structured as follows: Section 2 introduces the concept of occupancy heterogeneity and presents the motivation; Section 3 discusses the constraints for conditionally redistributing loads through occupant reassignment, and presents the objective of this paper; Section 4 describes the iterative reassignment algorithm based on agglomerative hierarchical clustering and different levels of constrains; Section 5 presents the case study used to demonstrate the need of integrating occupancy based control with occupant reassignment and the results; Section 6 discusses the limitations and concludes the paper.

2 OCCUPANCY HETEROGENEITY AND RESEARCH MOTIVATION

In general, the importance of occupants in a building's HVAC heating/cooling energy consumption can be broken down into two categories: Occupancy in a building (presence and number of occupants) and occupant actions in a building (how occupants behave) (Hoes et al. 2009; Yu 2010; Yu et al. 2011; Santin 2011). Occupancy results in heat gain as occupants continuously generate heat due to their metabolisms and activities. Occupancy is also associated with the use of other building systems such as lighting, and appliances such as computers, which radiate and add heat to the environment. Occupancy also determines active heating/cooling periods and thermal conditions. When the space is occupied, an HVAC system usually runs to maintain static and desirable thermal conditions. Occupants' actions also impact HVAC loads, for example interactions with building elements, such as blinds, windows, and doors. Since occupancy (presence and number of occupants in a zone) acts as the basis for occupant actions and determines the actual demands for HVAC heating/cooling (Andersen et al. 2009; Tabak and de Vries 2010; Masoso and Grobler 2010), this study focuses only on the occupancy related HVAC energy efficiency. Specifically, occupancy is defined as time-sequenced occupancy changes to represent how occupants occupy a space, including occupant presence and number, as defined in the introduction.

Occupancy based control operates HVAC setpoints based on actual occupancy. Motivated by the significance of inefficiencies in energy consumption, a range of studies have been undertaken to optimize HVAC setpoint controls based on real-time occupancy (Erickson et al 2011; Dong and Andrews 2009; Ghahramani et al. 2014; Oldewurtel et al. 2012). The basic principle is that energy efficiency could be improved by not fully running HVAC systems in vacant zones (Aswani et al. 2012; Gao and Whitehouse 2009; Yang et al. 2013). Instead, zone temperatures were allowed to float within a certain range (Agarwal et al. 2010). Therefore, for a single room, if occupancy based control is implemented, the nominal demands are approximately equal to actual demands except for the difference caused by the frequent system startups and reconditioning. However, a mechanical zone may consist of more than one room. At the zone level, real-time occupancy is determined by aggregating the occupancy status of rooms in that zone. When any room in the zone is occupied, active conditioning is required for that room, and the loads of the zone are the sum of loads in all rooms of that zone. Researchers have found that rooms of buildings may have different or in some cases inverse real-time occupancies as real-time occupancies are heterogeneous in nature (Wang et al. 2005; Page et al. 2008; Goldstein et al. 2010). This conclusion has been proven true in multiple test beds (Mahdavi 2009; Wang et al. 2011; Duarte et al. 2013). Simply aggregating disparate real-time occupancies might create an inaccurate representation of how each zone is occupied, and may fail to reduce the effective loads at the zone level and building level because the reduction of loads from one room is compromised by the additional requirement of other rooms and zones (Yang and Becerik-Gerber 2014a). In other words, the heterogeneity in occupancy may lead to the heterogeneous distribution of effective loads, and may reduce energy efficiency. Further, adjacent zones are sometimes served by the same supply air and there exist heat transfer and balance among zones. Therefore, the long-term occupancy should be integrated to the occupancy based control in order to reduce the loads resulting from heterogeneous real-time occupancy at the zone level as well as at the building level.

3 REDISTRIBUTION CONSTRAINTS AND RESEARCH OBJECTIVE

Occupancy profile, representing the long-term occupancy, is a typical-weekday/weekend presence probability as a function of time for a specific space. If there is more than one room in a zone, the occupancy profile for that zone is formulated by comparing the occupancy probabilities among all rooms in that zone at each time point, and by choosing the highest probability as the occupancy probability for that zone. In this paper, the occupancy profile is used as the measure to quantify the heterogeneity level of real-time occupancy, and to group similar occupancies for energy efficiency. There might be more than one profile representing one room (e.g., profiles for different days of the week) and there might be changes in a profile. However, considering reassignment is a one-time activity, all available occupancy information should be used to generate occupancy profiles, and it is assumed that an occupancy profile from a certain period of time could be representative in terms of clustering occupancy and regrouping occupancy-associated loads. If a space has more than one profile, the one representing for the majority of time is selected. In authors' previous work, an ARMA (AutoRegressive-Moving-Average)-based algorithm was developed and validated to model personalized occupancy profiles by analyzing the ambient environment and previous occupancy information (Yang and Becerik-Gerber 2014b). This algorithm is applied in this paper to prepare occupancy profiles for reassigning occupants and redistributing effective loads.

In the authors' previous research, load redistribution was also studied by reassigning occupants based on profile similarities at the zone level (Yang and Becerik-Gerber 2014a). It has been demonstrated that 5.4% of energy efficiency was improved by reducing the effective loads compared to simply implementing occupancy based control, indicating that the difference between nominal demands and actual demands has decreased. However, there is still room for further improvements if load redistribution could be integrated with an occupancy based control and extended from the zone level to the building level and with the following three factors being taken into consideration: (1) HVAC layout. Office buildings are commonly served by centrally controlled HVAC systems, and there might be more than one set of secondary HVAC system (e.g., air handling unit). The HVAC layout determines the zones with shared supply air. Zones under the same secondary HVAC systems should have similar occupancy profiles. (2) Zone adjacency: adjacent zones share boundaries and there are load exchanges through heat transfer and balance among the zones, when there is temperature difference. If the adjacent zones have distinct schedules for heating/cooling, unnecessary energy might be consumed due to thermal circulation. (3) Orientation: zones with the same orientation usually have similar boundary conditions and are impacted similarly by the outside environment. Unlike the zones on the perimeter, the zones in the core without outside surfaces are called core-orientation in this paper. Putting similar occupancy profiles onto the same orientation, and moving relatively low occupancy profiles (with small presence probabilities) to the perimeters of a building, could reduce the loads from heat gain/loss through a building's envelope and further improve the energy efficiency.

Generally, load redistribution by reassigning occupants is an easy and effective way to elevate the effects of an occupancy based HVAC control to further improve energy efficiency. This process is conditional, depending on the hierarchical constraints of occupant reassignment. Different levels of constraints should be considered in sequence, after the higher-level constraints being satisfied, the lower level constraints are to be included. If there is a conflict between the two sets of constraints, primary constraints are given the priority. Primary constraints for occupant reassignment could have several different rules, such as physical requirements, organizational limits, room functionalities and occupant preferences. Secondary constraint requires similar occupancy profiles to be assigned to the same zones so that the occupants of a zone could have similar presence patterns. The third constraint is similar occupancy profiles are to be assigned to the connected zones including adjacent zones, zones with same orientations and zones under the same secondary HVAC system.

The objective of this paper is to propose a framework to conditionally redistribute loads at the building level by reassigning occupants and integrate an occupancy based control with occupant reassignment. To test whether energy efficiency could be further improved compared to simply implementing an occupancy based HVAC control, simulation of a case study building is performed. It is important to note that these investigations do not aim to provide any specific reassignment solution for a specific building but instead they are used to demonstrate the need of integrating real-time occupancy and long-term occupancy for HVAC energy efficiency. The main contributions include the increase of our understanding about the impact of heterogeneous characteristics of occupancy on the difference between nominal demands and actual demands for heating and cooling, reduction of loads through the exploration of load redistribution by conditionally reassigning occupants, and potential for better-informed decision making for occupancy based HVAC control.

4 BUILDING LEVEL LOAD REDISTRIBUTION

A hierarchical clustering algorithm is designed to cluster occupancy profiles based on their similarities while considering the connectivity between clusters. Profiles that belong to a small cluster also belong to bigger clusters. Occupancy profiles are derived from real-time occupancy with irregular occupancy being eliminated. It has been demonstrated by the authors that real-time occupancy could be estimated by using the observable ambient factors, such as CO_2 concentration, temperature and light levels (Yang et al. 2013). The underlying assumption is that occupancy regularly influences the ambient environment. Thus, there exists a relationship between occupancy and the changes in the ambient factors. By mathematically or statistically modeling this relationship through supervised learning, future ambient data could be analyzed to output corresponding occupancy. This ambient sensing based modeling outperforms current methods of modeling occupancy, such as observations, surveys, short-term measurements or real-time end use monitoring, as these methods are not practical due to the intrusion they cause to buildings and their occupants, and they do not satisfy the requirements for detailed occupancy driven applications because of the lack of precision and consistency and verification in auditing. Using real-time occupancy to generate an occupancy profile is a mining process to find the mathematical or statistical patterns of occupancy, and may require further post-processing of raw profiling results. It is because actual occupancy has time continuity, which could be undermined by the outliers in the ground truth and impacts of irregular occupancy. In addition, conditioning effects of heating/cooling are not spontaneous and it takes some time to reach the desired temperature. Therefore, occupancy profiles for HVAC energy efficiency should be represented on a time-window basis. A logic operation is designed in this paper for updating an occupancy profile. Specifically, sliding windows are defined to segment the profiles by time windows with overlaps. The averaged presence probability within each window is then used as the feature for this window to form a new feature vector (updated profile) for similarity analysis. This logic operation could also reduce the dimension of a feature vector, which improves the computational efficiency and the reliability to compare the similarity among occupancy profiles.

The clustering process starts by assigning each updated profile to an individual cluster, each containing only one profile. The Minkowski distance is used to calculate the similarity between two profiles, as it is used as a general function to measure distance in clustering.

$$\text{Minkowski distance } d_{ij} = \sqrt[r]{\left(\sum_{k=1}^{n} |x_{ik} - x_{jk}|^r\right)}$$

In which, d_{ij} is the distance between profile *i* and profile *j*; *n* is the vector dimension, depending on the length and overlap of the sliding window; x_{ik} is the averaged probability of window *k* for the profile *i*, and x_{jk} is the averaged probability of window *k* for the profile *j*. *r* is selected as 2 in this paper thus the Minkowski distance becomes Euclidean distance. The distance between two clusters is defined as the average of all distances between any inter-cluster profile pairs. All pairs are searched to find the closest pair of clusters and they are merged into a single cluster. Following this procedure, there is one cluster less. Then the distances between the new cluster and each of the old clusters are computed. These agglomerative hierarchical clustering steps are repeated until all profiles are clustered into a single cluster.

Based on the hierarchical clustering, an iterative reassignment algorithm is then designed to complete the conditional reassignment, depending on the hierarchical constraints of occupant reassignment (Figure 1). First, all of the profiles are assigned into initial clusters based on the primary constraints. This step varies case by case and there might be more than one primary constraint to be considered. For different initial clusters, the occupant reassignment is conducted independently. Within each initial cluster, the agglomerative clustering is then used to merge two clusters one at a time according to their profile similarities. Initially, the first two profiles to be merged are randomly assigned to one zone. If the new cluster contains the cluster merged in the previous step, the subsequent profiles are assigned to the same zones of the existing profiles or connected zones depending on whether the zone capacity has been reached and how the third constraints (zone adjacency, orientation, and HVAC layout) define the divisions of connected zones. Otherwise they are assigned to the zones containing the profiles that are relatively most similar to the subsequent profiles. As long as two clusters are merged to one cluster, profiles within one zone are adjusted to ensure the profiles on the zone boundaries are similar to the profiles on the boundaries of the connected zones. Finally, all profiles are merged to a single cluster and one trial of reassignment is then completed. Since the initial assignment point is randomly selected, the entire process described above is iterated with different initial assignment points until the ratio between inter-zone distance and inner-zone zone reaches the maximum.

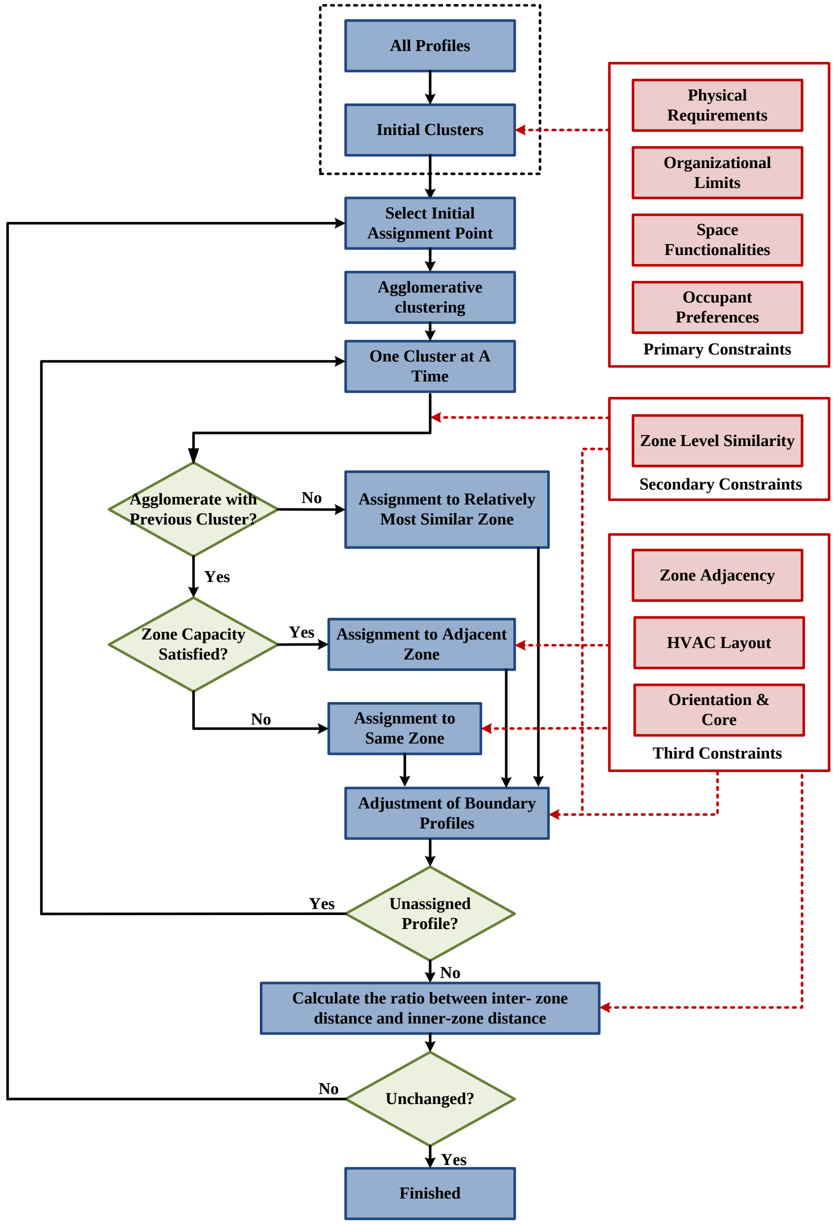

Figure 1: Iterative algorithm for hierarchical clustering and occupant reassignment.

5 REDISTRIBUTION AND RESULTS

The case study building for validating the iterative reassignment algorithm is the Ralph & Goldy Lewis Hall (RGL), a typical office building on the University of Southern California (USC) campus near downtown Los Angeles, California. The RGL is a three-story building with a footprint of 3,735 m^2 with 89 mechanically conditioned rooms that have spaces of varying sizes and functions. Most of the rooms in the building are enclosed single occupancy offices; other rooms are classrooms, conference rooms, and auditoriums. The building is equipped with state-of-the-art BEMS (Building Energy Management System) and central HVAC system with air handling units (AHU) serving a total of 64 variable air volume (VAV) boxes and 3 fan-coil units (FCU). A VAV box is responsible for regulating the ventilation in the thermal zone with conditioned air, and reheating the air with hot water supplied by the boilers if the zone needs heating instead of cooling. The conditioned air is supplied to the VAVs by air handler units (AHUs) using fans and ductwork. There are two AHUs in the building, each servicing one side of the building with similar sizes of service areas. According to the thermal properties of different surface boundary conditions, there is less significant heat transfer through floors compared to the walls. Therefore, load redistributions at different floors were assumed to be independent and only the third floor of the test bed building was used to represent the building level load redistribution. The 16 zones on the third floor consist of 28 rooms and were monitored by 28 wireless sensor units, each of which includes a number of ambient sensors such as temperature sensor and CO_2 sensor for modeling real-time occupancy (Figure 2).

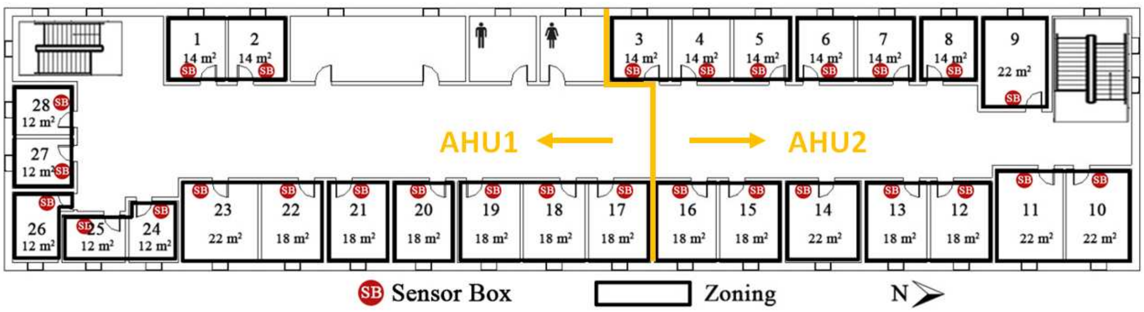

Figure 2: Zones and rooms on the third floor of the case study building.

To simplify the reassignment process, in this paper, the primary constrains were only set for physical requirements including room size and zone capacity. Specifically, an occupant could be assigned to a room no larger or smaller than 20% of the size of his/her original room, and the number of occupants in each zone cannot change before or after the reassignment. The selection of specific constraints does not influence the way of reassigning occupants and can be further extended to include other constraints, such as space functionalities, occupant preferences, and so on. The secondary constraint places similar occupancy profiles in the same zones. Since the HVAC loads at the zone level are the sum of loads in all rooms of that zone, redistributing the loads may unify the periods of effective loads and improve energy efficiency. The ARMA-based algorithm (in Yang and Becerik-Gerber 2014b) was used to calculate the presence probability at each time point for the 4 months (from January to April 2013). Since the sampling rate for the real-time occupancy model was 3 minutes, the original occupancy profile was 480-dimensional (Figure 3). The logic operation was determined to segment the 480 dimensions by a 30-minute time window with 15-minute overlap and the period from 6:30 AM to 9:30 PM (HVAC on-hour mode time) was chosen to form a 60-dimensional vector. Each number in the vector was the averaged presence probability for the corresponding 30-minute time window (Figure 3).

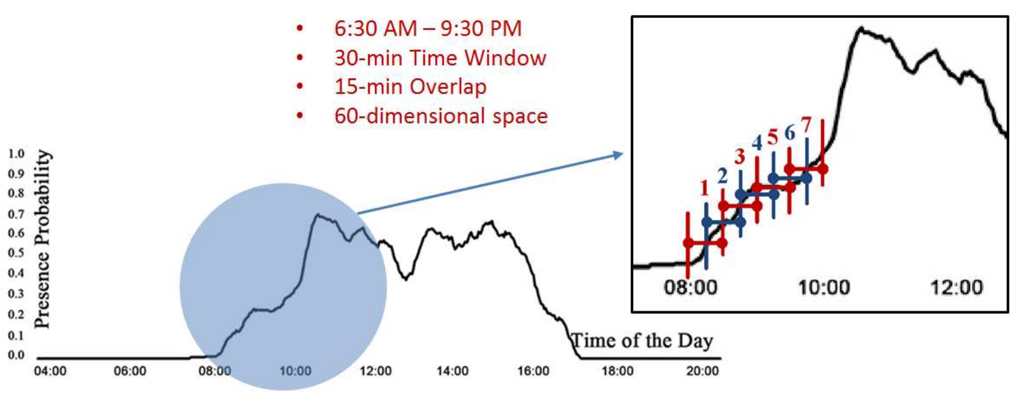

Figure 3: Original occupancy profile and logic operations applied to form an updated occupancy profile.

The third constrain required the occupancy profiles in the connected zones to be similar. Considering the zone adjacency, zone orientation (North, South, East, West, and there is no Core Zone in this building), and HVAC AHU coverage (Figure 2), the third floor of testbed building was divided into six connected zones (Figure 4).

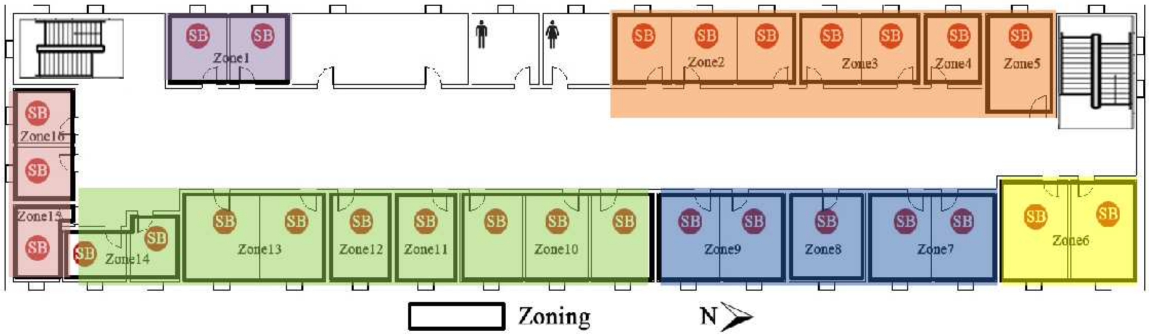

Figure 4: Connected zones of third floor determined by the third constraints.

Matlab was used to implement the hierarchical clustering and occupant reassignment for the 28 occupancy profiles. The final occupant reassignment plan is shown in Figure 5.

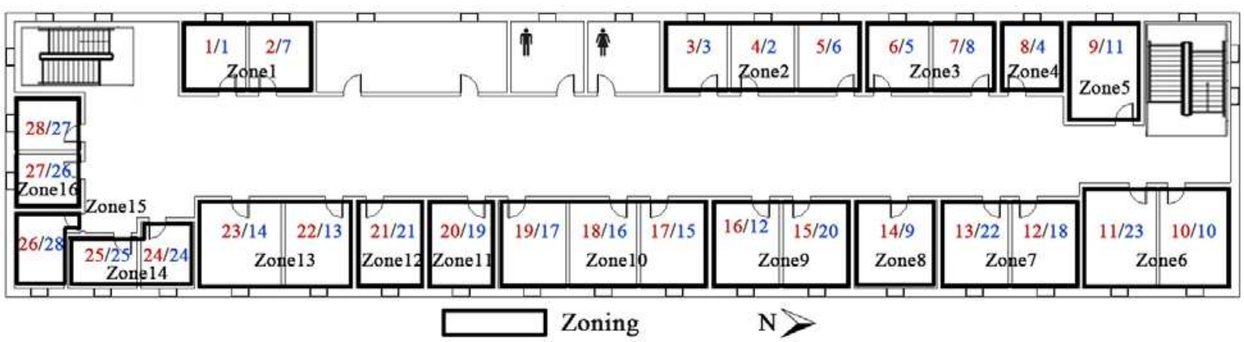

Figure 5: Occupant reassignment plan based on iterative reassignment algorithm (numbers in red represent the profile number before the reassignment and numbers in blue represent the profile number after the reassignment).

In order to investigate the energy implications at the building level, an occupancy based control was simulated before and after occupant reassignment and the corresponding energy consumptions were compared with a baseline control. The baseline is the control used in the building, and it assumes all thermal zones in the building to be always occupied under the on-hour mode (6:30 AM - 9:30 PM on workdays, and 7:00 AM - 9:30 PM on weekends), and a constant temperature set point of 73F (296 K) is maintained. Occupancy based control requires a setpoint being programmed to float to a setback when the zone is unoccupied (e.g., during lunch breaks, etc.), and intermittently go back to setpoint during the occupied periods under the on-hour mode. Additionally, the period of on-hour model should be updated with the start-up time being as close as possible to the time the space is first occupied, and the stop time being soon after the time the space becomes unoccupied for the day. So that, the uniformity of terminal start time/stop time schedules and synchronization of intermittent conditioning could be both considered. First, based on occupancy profiles, the terminal control start schedule was set from aggregated room occupancy profiles as the first time when the presence probability of any room became positive (above 0) in a zone, and the stop schedule was the last time when the presence probability of all rooms became 0 in that zone. Second, during the on-hour mode, an occupied mode was enforced for the zones with at least one room being occupied, where a constant temperature set point of 73F (296K) was maintained. If a zone stays vacant for a minimum of 15 minutes, a vacant mode was triggered, where the temperature set point was set back to 78F (299K) until it became occupied again. For both baseline control and occupancy based control, during the off-hour period, no cooling or heating services was provided. Only minimum airflow was maintained to satisfy the ASHRAE compliance (ASHRAE 2010).

Energyplus was used as the simulation program to simulate the energy implications of the occupancy based control and occupant reassignment as it could provide strict heat balance and a simultaneous solution for LSPE (load, system, plant, economic) (Yang and Becerik-Gerber 2014c). A total of 12 months from January to April 2013, and from March to November 2014 were chosen because of the availability of actual occupancy data, and were simulated through a well-calibrated energy model (Yang and Becerik-Gerber 2015). First, the baseline control was simulated for benchmarking, then the occupancy based control before and after occupant reassignment were simulated. The heating/cooling energy consumptions for the three scenarios were compared. The energy reduction percentages of occupancy based control before and after occupant reassignment compared to the baseline control were shown in Figure 6.

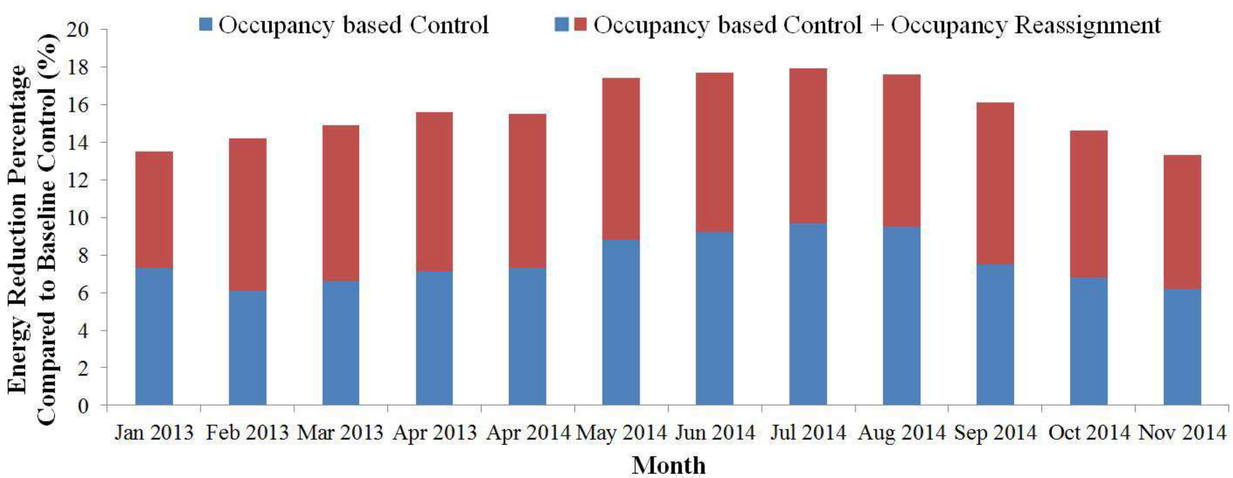

Figure 6: Simulation results for the energy implications of occupancy based control and occupant reassignment.

It can be seen from the results that HVAC energy consumption has been significantly reduced by implementing both occupancy based control and occupant reassignment. Occupancy based control could save more energy during the winter recess and the summer (Jan 2013, May -Aug 2014, respectively) while the occupant reassignment was more effective in fall semester (Sep – Nov 2014) and spring semesters (Feb – April 2013, April 2014, respectively) for improving energy efficiency. In general, occupant reassignment could almost double the effects of occupancy based control by elevating the uniformity of terminal start time/stop time schedules and synchronization of intermittent conditioning. It was demonstrated that the integration of occupancy based control and occupant reassignment could unify the nominal demands with actual demands especially for the months when cooling is dominant in Los Angeles (May – Sep 2014). The results also show that loads are impacted by the occupancy heterogeneity and occupant reassignments influence the load redistributions. The proposed iterative reassignment algorithm reduced unnecessary loads and improved HVAC energy efficiency by 18.9% compared to the baseline control currently used in the building, by 9.6% compared to simply applying occupancy based control, and by 4.2% compared to the zone level occupant reassignment (Yang and Becerik-Gerber 2014a). The occupancy profiles were formulated using the occupancy data in 2013. However, there was no significant difference of energy savings between the simulation results of 2013 (Jan – April 2013) and the results of 2014 (Mar – Nov 2014), the assumption that occupancy profile from a certain period of time could be representative enough in terms of clustering occupancy and regrouping occupancy-associated loads, could be true for this case study. It could also be concluded that occupancy heterogeneity in terms of load representation stays constant over time and this characteristics is effective to group and reassign occupants for leveraging occupancy based HVAC control.

6 CONCLUSIONS

This paper presented a framework to conditionally redistribute loads at the building level by reassigning occupants in order to elevate the effects of occupancy based control, and simulated an office building with actual occupancy information as a case study for validation. Since HVAC loads at the terminal level are the sum of loads in all rooms of a zone, redistributing the loads could unify the periods of effective loads and improve energy efficiency. In addition, similar occupancy profiles could be gathered together in the zones that are adjacent, that have the same orientation and/or are under the same secondary HVAC systems to further reduce the total loads at the building level. As load redistribution through occupant reassignment is a conditional and hierarchical process, predefined requirement constraints (e.g., room size) and capacity constraints (e.g., number or rooms within a zone) were considered. An agglomerate hierarchical clustering based algorithm was designed for iteratively assigning occupancy with zone adjacency, orientation, and HVAC layout being considered. It was demonstrated that heterogeneous distribution of loads, resulting from heterogeneous occupancy, leads to HVAC energy inefficiency. The results also demonstrated that effective loads at the building level were significantly reduced by up to 18.9%. These reductions are from the uniformity of terminal start time/stop time schedules and synchronization of intermittent conditioning compared to the baseline control currently used in the building. Up to 9.6% of energy consumption could be saved compared to simply implementing occupancy based HVAC control . It was demonstrated that the proposed load redistribution framework could outperform zone level reassignment to unify the nominal demands with actual demands, reduce the unnecessary energy transfer, and improve energy efficiency by additional 4.2%. It is important to note that these investigations do not aim to provide specific reassignment solutions for a specific building but instead they are used to demonstrate the need of integrating real-time occupancy and long-term occupancy for HVAC energy efficiency. The main contribution of this paper is to increase our knowledge about the impacts of heterogeneous characteristics of occupancy on the difference between nominal demands and actual demands for heating and cooling, and to reduce loads through the exploration of load redistribution by conditionally reassigning occupants, for enabling better-informed decision making for occupancy based HVAC controls.

However, there are limitations and they are outlined here for future explorations. The energy consequences of integrating occupancy based control and occupant reassignment were considered to effectively represent the energy implications of occupancy heterogeneity, which requires further validation through conducting other reassignments simply based on primary constrains and random assignments. In addition, only the room area was analyzed as the primary constraint in this paper, when more primary constraints are added, there might not be any available solution for reassignment. Finally, the agglomerative hierarchical clustering process should be further optimized to reduce the time and computational complexity for occupant reassignment.

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