A PROCESS FOR MICRO-ZONAL OCCUPANT-CENTRIC CONTROL (MZOCC) FOR ENERGY-EFFICIENT AIR CONDITIONING IN LARGE ROOMS.

FIELD OF THE INVENTION:

The present invention relates to localized air-conditioning of a large area. More specifically, the present invention is directed to develop a process to control localized air-conditioning of the occupied regions in a large room to reduce HVAC energy consumption. The invention consists of bi-level protocols to optimize localized air conditioning to consume minimum energy consumption. In the present process, the room is divided into virtual micro-zones following the first level of protocols. The second level of protocols gives guidelines to control airflow through diffusers in the occupied and unoccupied micro-zones to achieve setpoint temperature or thermal comfort in the occupied regions using minimum HVAC energy.

BACKGROUND OF THE INVENTION:

Occupant-Centric Control (OCC) of air conditioning systems is a smart air conditioning method by which the controller identifies the occupancy conditions and operates the air conditioner to create comfortable conditions only in occupied thermal zones (Pang et al., 2020). OCC is usually employed using zone level air-conditioning system where a room is considered as the smallest unit of thermal zone. With modern buildings featuring large rooms unhindered by partitions, few methods of virtually dividing thermal zones into micro-zones have been explored. Two common methods are (1) using personalized ventilation (PV) (Melikov, 2004) or personal comfort systems (PCS) (Rawal et al., 2020) that uses personal fans or AHUs placed very close to occupants to create micro-zones of comfort. The type of airflow and size of micro-comfort zone created depends on the air terminal device (ATD) used. The second method is to virtually divide a thermal zone into sub-zones and allow OCC using standard HVAC diffusers. Sub-zones are developed by dividing the thermal zone on the basis of the total number of diffusers in the zone (Nagarathinam et al., 2017). This division does not consider the functional planning of the space or spread of air jets from the diffusers,

whereas these are considered in micro-zoning. The size of micro-zones can be defined to be larger than the micro-comfort zones created using PV, but smaller than sub-zones discussed in existing literature (Jacob et al., 2023a). Employing Micro-Zonal Occupant-Centric Control (MZOCC) is established to reduce air conditioning energy consumption in large multi-occupant thermal zones (Jacob et al., 2023c).

The parameters such as diffuser type, location of diffusers, partition heights, air movement, inter-micro-zonal interaction, variations in thermal preferences, occupancy pattern, etc. are important in MZOCC. The micro-zonal layouts are to be planned considering the functional planning of the zone and the spread of air jets from diffusers. The minimum area required for different activities and the area served by different diffuser types have been tabulated by performing a survey of several open-plan offices in India (Jacob, Pandit, et al., 2024d).

In the absence of physical partitions, cool air easily escapes out to the unoccupied regions. There is a need to tune the parameters which influence spatial design of the zone and airflow through diffusers to reduce this inter-micro-zonal interaction. Uncontrolled inter-micro-zonal interaction can lead to excessive merging and deflection of cool air from occupied micro-zones (Jacob et al., 2023c), convergence of air jets below or near the supply diffusers (Jacob et al., 2023c; Jacob, Pandit, et al., 2024a), immediate escape of cool air from supply to return diffuser (Jacob et al., 2022; Jacob, Pandit, Debapratim, et al., 2024) and can also cause thermal discomfort due to draft or horizontal and vertical thermal gradients (Jacob et al., 2023b; Jacob, Pandit, et al., 2024b). The factors leading to such deflection of air jets and the associated wastage in energy consumption has been evaluated using validated CFD simulations.

Literature discusses three airflow control strategies to avoid the aforementioned issues. These were developed using extensive CFD based analysis of air distribution under different airflow control strategies. They are (1) using Setback Flow (SBF) or low velocity flow in unoccupied micro-zones. The low velocity flow

influences the high velocity flow in occupied micro-zones, thereby increasing the spread of air jets in occupied micro-zones. This addresses issues of attachment of air-jets and convergence of air jets. The next strategy is (2) to maintain a Setback Temperature (SBT) or increased setpoint temperature in unoccupied micro-zones. In this the unoccupied micro-zones are cooled to a setback temperature using maximum allowed flow and the flow is stopped on attaining setback temperature. This helps in reducing the temperature difference between occupied and unoccupied micro-zones and helps in controlling inter-micro-zonal interaction, merging of air jets and avoiding high thermal gradients. The third strategy is to use Alternated Flow (AF). This is used to avoid excessive merging and deflection of air jets when multiple adjacent diffusers are operated simultaneously. In this, one diffuser is operated at full velocity while the adjacent diffuser is operated at low velocity. This helps in increasing the spread of air jets in the micro-zones with diffusers with full flow. After few mins (say 2 mins), the airflow in diffusers with full flow are reduced and the others are increased to full flow. This helps in channelizing cool air to the micro-zones which now has full flow. Thus, the operation is alternated every 2 mins until comfortable conditions are attained in all occupied micro-zones.

The airflow strategy used needs to be changed if thermal discomfort is observed. Thermal discomfort can be due to PMV values not being within the comfort limit, draft discomfort and horizontal and vertical thermal gradients. The method of evaluating thermal comfort from information on air temperature, velocity and humidity within micro-zones are detailed in literature (Jacob et al., 2023b; Jacob, Pandit, et al., 2024b). Hence each micro-zone must be equipped with air temperature, humidity and velocity sensors, in addition to occupancy sensors to gather real-time information of the conditions in the micro-zones.

Occupant behavior models are to be used to estimate the occupancy schedule. Occupancy information can be checked as per the frequency of change of occupancy or occupancy sensors can be configured to send information to a server on observing changes in occupancy. Appropriate airflow control strategies

must be initiated on detecting occupancy. The process of selecting appropriate strategies are given in this invention. Indoor conditions can be monitored at lower time intervals such as 5-10 mins and airflow control must be improved if thermal discomfort is observed.

Thus, from literature, it is understood that micro-zoning can be optimized by designing micro-zones of appropriate size corresponding to the activities in the zone and the airflow from diffusers. Airflow can be strategized to achieve thermal comfort around occupants (Jacob, Pandit, et al., 2024c). Despite this, there is no well-defined process to optimize micro-zones or to plan airflow control.

Previous inventions give methods to control airflow at zonal and micro-zonal levels. US11778423 uses zone level information to control HVAC systems to reduce contaminants in a room. TWM656009 by Johnson controls, discloses a cloud-based smart air conditioning system that can optimize air-conditioning based on zone-level occupancy information. JP7337271B2 gives a method to use CFD simulations to plan optimal setpoints in individual rooms. Several other inventions such as WO2024146527, US11994307, US9599382 (B2), US 20180267701 A1, US 9104211 B2 discloses methods of controlling air conditioning in thermal zones. WO2020183445 (A1) discloses a prototype of micro-environments suitable to improve comfort conditions of occupants. A novel enclosure type, a luggage auto lift, a deodorization system and a climate control system are proposed in WO2020183445 (A1).

At micro-zonal level, personal comfort systems (PCS) or personalized ventilation (PV) devices have been developed. US 11188103 B2 discloses a PCS which has a personal air handling unit that can be placed on furniture to locally air condition the occupants. This PCS functions in addition to the ambient room air conditioning system. Most of the other inventions on personal control of air-conditioning are developed for automobiles.

There is a need to develop smart control systems for standard HVAC infrastructure to allow localized air-conditioning.

US9644857B1 discloses a method of using a virtual thermostat to control HVAC. The system can sense occupancy, decide the area to be conditioned in the thermal zone and control the operation of diffusers to cool the target area. Despite this, this disclosure does not give direction on how airflow must be controlled to reach comfortable conditions around the target area. Airflow can deflect from its expected path due to variety of reasons discussed earlier. Hence, allowing a system to explore variety of airflow control options increases the time required to cool the target region and may also increase energy consumption and thermal discomfort.

The present invention aims to address this issue by disclosing a set of protocols to be followed to control airflow in localized air-conditioning methods such Micro-Zonal Occupant Centric Control (MZOCC).

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OBJECT OF THE INVENTION

It is thus the basic object of the present invention is to provide a process to control localized air-conditioning of the occupied regions in a large room to reduce HVAC energy consumption.

Another object of the present invention is to provide a process to plan Micro-Zonal Occupant-Centric Control in large thermal zones to reduce energy consumption using standard HVAC infrastructure with ceiling diffusers.

Another object of the present invention is to provide a process to control localized air-conditioning in large thermal zones using bi-level protocols to plan virtual micro-zones within thermal zones and individually control diffusers in occupied and unoccupied micro-zones to reduce HVAC energy consumption without compromising thermal comfort.

SUMMARY OF THE INVENTION

Thus, according to the basic aspect of the present invention there is provided a process to implement and control localized air-conditioning of occupied regions in large confined space to reduce HVAC energy consumption comprising

delineating the space into multiple micro-zones based on a first level of protocol and static parameters thereof including planned activities, occupancy patterns, diffuser characteristics, and furniture layout;

controlling airflow through diffusers in the occupied and unoccupied micro-zones to achieve setpoint temperature or thermal comfort only in the occupied regions using minimum HVAC energy through implementing a second level of protocol with dynamic parameters relating to the micro-zones including real-time occupancy, thermal comfort preferences, ambient conditions, and inter-micro-zonal thermal interactions.

In the above process, step of controlling airflow through diffusers in the occupied and unoccupied micro-zones includes

detecting occupancy within one or more of the micro-zones using environment sensors;

involving diffusers and selectively controlling such diffusers for anyone or more of providing full airflow to occupied micro-zones, setback airflow to first and optionally second layer of adjacent unoccupied micro-zones, and stopping airflow in other unoccupied micro-zones;

monitoring temperature gradients and occupant comfort conditions through sensors within each occupied micro-zone and accordingly adjusting the airflow to a maintenance level in occupied micro-zones once setpoint temperature is achieved;

selectively alternating full and setback airflow among adjacent micro-zones in cases where multiple micro-zones are simultaneously occupied, to minimize jet convergence and reduce HVAC energy consumption.

In the above process, delineating the space into multiple micro-zones includes micro-zoning the confined space which is preferably an open-plan indoor environment by separating its externally heated core and internally heated perimeter following standard core-perimeter zoning strategy ensuring space is divided into a number of micro-zones according to planned activities and the micro-zones are forming a grid with size chosen based on area required for different activities.

In the above process, diffusers are selected based on the grid size and also the grid size can also be adjusted considering the area that can be catered by individual diffusers and the minimum distance between diffusers considering the spread of air jets;

wherein, if the size of each micro-zone corresponds to the standard spread of air jets from the selected diffusers, one supply diffuser is to be provided for each micro-zone, otherwise number of diffusers is obtained by dividing the area of the micro-zone with the area catered by a single diffuser considering the standard spread of air-jets and rounding off to the next highest whole number.

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In the above process, furniture arrangement in the confined space is re-organized such that micro-zonal boundaries do not cut through occupants.

In the above process, micro-zones are defined to ensure that inter micro-zonal boundaries avoids overlapping with planned occupant positions or seating in the space as per the first level of protocol and the static parameters, whereby adjacent micro-zones with similar activity, occupancy schedule and thermal comfort preferences or setpoint temperature is merged to a single micro-zone.

In the above process, positions of return diffusers are determined by involving drawing imaginary circles of radii equal to the standard spread of air-jets around the supply diffusers and placing the return diffusers outside or at the boundary of the imaginary circle, such as that the air jets will try to move towards the return diffusers and hence the location of return diffusers define the shape of the region with cool air in the micro-zone.

In the above process, when several adjacent micro-zones are to be conditioned or the entire zone is to be conditioned, same volumetric flow through all the diffusers and related excessive merging of air-jets is avoided by using 'Alternated Flow' strategy, whereby, one diffuser is operated a full velocity while the adjacent diffuser is operated at a low velocity for increasing the spread of air jets in the micro-zones with diffusers with full flow and after few mins, the airflow in diffusers with full flow are reduced and the others are increased to full flow for channelizing cool air to the micro-zones which now has full flow and the alternate flow is repeated until comfortable conditions are attained in all occupied micro-zones.

In the above process, thermal comfort is continuously evaluated using Predicted Mean Vote (PMV) values and draft prediction models to determine if maintenance flow is sufficient.

In the above process, expected occupancy is predicted using a data-driven occupancy behavior model.

According to a further aspect of the present invention there is provided a system to implement and control localized air-conditioning of occupied regions in large confined space to reduce HVAC energy consumption comprising

a micro-zonal layout module configured to divide indoor environment of the large confined space into multiple micro-zones;

a set of supply and return air diffusers positioned within said micro-zones, wherein each supply diffuser is associated with at least one return diffuser placed based on the spread of air jets to control airflow patterns;

a control unit configured to execute bi-level control protocols involving

(i) a first level of protocols for determining optimal micro-zonal layouts based on static parameters including diffuser spread, thermal loads, activity areas, and inter-zonal interactions and accordingly driving the micro-zonal layout module; and

(ii) a second level of protocols for dynamically controlling airflow within each micro-zone by controlling the set of supply and return air diffusers based on real-time occupancy, predicted occupancy, temperature readings, and thermal comfort preferences targeting minimization of HVAC energy consumption by selectively adjusting airflow in occupied and unoccupied micro-zones using strategies including setback flow, full flow, alternated flow, and maintenance flow.

The above system includes environmental sensors including at least three vertically spaced temperature sensors per micro-zone to monitor temperature, velocity, and humidity at multiple heights.

In the above system, the return diffusers are positioned outside or at boundary of imaginary circle of radii equal to standard spread of air-jets around the

corresponding supply diffusers such as that air jets will try to move towards the return diffusers and hence the location of return diffusers define the shape of the region with cool air in the micro-zone.

In the above system, the control unit receives occupancy information within one or more of the micro-zones from the environment sensors and accordingly sets the supply air diffusers (i) at full airflow to occupied micro-zones, setback airflow to first and optionally second layer of adjacent unoccupied micro-zones, and stop airflow in other unoccupied micro-zones;

wherein said control unit further monitors temperature gradients and occupant comfort conditions through the sensors within each occupied micro-zone and accordingly adjusts the sets the supply air diffusers for an airflow to a maintenance level in the occupied micro-zones once setpoint temperature is achieved including selectively alternating full and setback airflow among adjacent micro-zones in cases where multiple micro-zones are simultaneously occupied, to minimize jet convergence and reduce HVAC energy consumption.

In the above system, when several adjacent micro-zones are to be conditioned or the entire zone is to be conditioned, the control unit sets one supply diffuser at a full velocity while the adjacent supply diffuser is operated at a low velocity for increasing the spread of air jets in the micro-zones with diffuser with full flow and after few mins, the control unit reduces airflow in that diffuser with full flow and set the other diffuser at full flow for channelizing cool air to the micro-zones which now has full flow, whereby the control unit repeats the alternate flow until comfortable conditions are attained in all occupied micro-zones.

In the above system, the micro-zonal layout module set the micro zones based on area that can be catered by individual diffusers, minimum distance between

diffusers considering the spread of air jets and inter micro-zonal boundaries avoids overlapping with planned occupant positions or seating in the space as per the first level of protocol and the static parameters, whereby adjacent micro-zones with similar activity, occupancy schedule and thermal comfort preferences or setpoint temperature is merged to a single micro-zone.

BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS :

Figure 1. Pictorial representation of Micro-Zonal Occupant-Centric Control

Figure 2: Defining adjacent micro-zones

Figure 3: (a) Plan and (b) Section of micro-zones

Figure 4. Working of alternated flow strategy

Figure 5: Schematic diagram of the process disclosed in the invention

Figure 6: Detailed scheme of the bi-level process of MZOCC

Figure 7a. Layout of the case study office

Figure 7b: Interior views of the case study office

Figure 8: Possible micro-zonal layouts

Figure 9: Micro-zonal layout planned using the protocols

Figure 10: Thermal countors for case 1 evaluation

Figure 11: Thermal contours for case 2 evaluation.

DESCRIPTION OF THE INVENTION WITH REFERENCE TO THE ACCOMPANYING DRAWINGS:

The present disclosure gives bi-level protocols for Micro-Zonal Occupant-Centric Control. MZOCC is a futuristic smart air-conditioning planning and control system that can detect occupancy, prevailing indoor conditions, thermal preferences of occupants, estimate inter-micro-zonal interaction and control air-conditioning in each micro-zone as per requirement. A schematic diagram of MZOCC is shown in Figure 1. Such a system can reduce about 60% HVAC energy consumption with minimal additional investment.

The micro-zonal layout, diffuser arrangement, furniture design and their arrangement are planned considering the static parameters influencing MZOCC such as, zonal layout, planned activities, planned occupancy, area required for each activity, characteristics of the diffusers, furniture used, etc. Once planned, these cannot be altered and hence, the air distribution and inter-micro-zonal interaction under various airflow control strategies considering variety of occupancy scenarios are also considered while finalizing these static design parameters. On performing extensive CFD simulations in six layouts of open-plan offices, strategies to plan these static parameters have been formulated. The scenarios considered in CFD simulations included changing diffuser location, occupancy conditions, location of occupied micro-zones etc. Hence additional CFD simulations need not be performed while planning micro-zones using the derived strategies.

Strategies to plan the same constitutes the first level of protocols. The second level of protocols gives strategies for planning airflow control considering the transient changes in occupancy, heat gained, thermal comfort preferences, ambient conditions, etc. the protocols help in deciding the best airflow control strategy for a given occupancy scenario in a given open-plan office.

There is also a need to continuously strategize airflow considering the predicted changes in the zone. The present disclosure gives protocols for micro-zoning and protocols for airflow control. A systematic method to plan MZOCC using the proposed bi-level strategies is also disclosed.

The idea of developing protocols for planning micro-zonal layouts is to reduce the dependence on CFD simulations to shortlist suitable strategies for MZOCC from numerous possible micro-zonal layouts and airflow control options. Hence, several assumptions derived from literature are used while employing the protocols. The protocols are developed from CFD based analysis performed in six open-plan offices in India of sizes varying from small to large. The developed protocols are evaluated in large open-plan office by assuming two scenarios of occupancy conditions for a typical working day.

The invention gives a set of guidelines to be followed (1) while planning micro-zones and (2) for controlling airflow through diffusers. A systematic method of planning MZOCC using the proposed bi-level protocols is also disclosed. The potential of using the aforementioned protocols is evaluated for a case study open-plan office and the results show that about 60% air conditioning energy can be saved by using MZOCC compared to conventional air conditioning practice.

The first level of protocols gives guidelines to plan micro-zones. In this, first the best micro-zonal layout is selected by considering the characteristics and activities in the zone. From an extensive survey performed in forty open-plan offices in India, the typical area required for different activities and the area catered by different diffuser types are given in Tables 1 and 2

Table 1: Area required for different activities in an office

Activity Type	Grid (m)
Rectangular or circular workstations (4-seater facing each other)	3x3
Workstations attached to walls or pillars	offset of 2m from surface
Meeting spaces - 12 people	5x4
Collaborative spaces	2x1.5
Waiting area	2x2
Lounges	2x2
Activity Based Work environments- Individual Couches	3x1.5
Activity Based Work environments - Work cafes	6x9
Activity Based Work environments - Swing tables	4x4

Table 2: Area catered by different diffuser types

Diffuser Type	Grid (m)
4-way square ceiling diffuser	3x3
Cassette units	6x6
Rectangular grills	1x4
Circular diffusers	radius of 1.5

The process of selecting micro-zonal layouts is included in the first level of protocols. On selecting the best micro-zonal layout, considering the occupancy condition, the sequence of using SBF, SBT or AF must be explored. This constitutes the second level of protocols.

The first layer of adjacent micro-zones are defined as micro-zones sharing virtual boundary with the occupied micro-zones. This is shown in Figure 2a. The second layer of adjacent micro-zones are micro-zones sharing virtual boundary with the first layer of adjacent micro-zones and is highlighted in Figure 2b.

The thermal zone shown in Figure 3 is divided into 6 micro-zones. If micro-zone 1 (MZ1) is occupied, then MZ2 becomes the first layer of adjacent micro-zone and MZ4 becomes the second layer of adjacent micro-zone as shown in Figure 3. Following the protocols, full flow will be maintained in MZ1, setback flow in MZ2

and no flow in MZ4. This is illustrated in Figure 3b. Environment sensors (temperature, velocity and humidity sensors) are to be placed at the center of each micro-zones at heights 0.6m, 1.1m and 1.7m to measure vertical thermal gradients. These sensors can be placed on the furniture. Temperature sensors are to be placed at the micro-zonal boundaries at heights 1.1m to measure horizontal thermal gradients. The invention is explained in the following sections. Section 1 lists the protocols and section 2 gives a flow chart depicting a how MZOCC can be planned with a thermal zone.

Section 1: Protocols for MZOCC

1. Strategies for planning micro-zones

a. Start micro-zoning by separating the externally heated core and internally heated perimeter following standard core-perimeter zoning strategy (ASHRAE 2017).

b. The space must then be divided into micro-zones according to planned activities, and the micro-zonal grid size must be chosen based on the area required for different activities.

c. Diffusers must then be selected based on the grid size. The grid size can also be adjusted considering the area that can be catered by individual diffusers and the minimum distance between diffusers considering the spread of air jets.

d. The furniture arrangement needs to be re-organized such that micro-zonal boundaries do not cut through occupants.

e. Adjacent micro-zones with similar activity, occupancy schedule and thermal comfort preferences or setpoint temperature can be merged to a single micro-zone.

f. Placing ceiling lights between supply diffusers slightly increases the spread of air jets, but does not cause any significant change and hence can be placed anywhere between diffusers.

g. If the size of each micro-zone corresponds to the standard spread of air jets from the selected diffusers, one supply diffuser is to be provided for each micro-zone. Else, the number of diffusers is obtained by dividing the area of the micro-

zone with the area catered by a single diffuser considering the standard spread of air-jets and rounding off to the next highest whole number.

h. To plan the location and design of return diffusers, the following strategy must be adopted

i. Draw imaginary circles of radii equal to the standard spread of air-jets around supply diffusers.

ii. Place return diffusers outside or at the boundary of the imaginary circle

iii. Air jets will try to move towards the return diffusers and hence the location of return diffusers define the shape of the region with cool air in the micro-zone.

1. For example, placing square shaped return diffusers in the corner of the micro-zones leads to cool air spreading in an 'X' shape.
2. Linear return grill diffusers on all sides of four-way square ceiling diffusers helps in creating square shaped micro-zones of approximate size 3m x 3m.
3. For linear grill supply diffusers, linear grill return diffusers can be placed outside the spread of air jets. The spread of air jets for different diffuser types are given in Table 2 .

i. Once the diffuser and furniture layout are finalized, the height of partitions must be planned considering inter-micro-zonal interactions for different occupancy scenarios. The height of partitions can be between 30cm to 80cm from the table.

2. Strategizing airflow control

a) If the zone has been unconditioned for a long time, before few minutes (about 2-5 mins) of actual occupancy, the micro-zones where occupancy is expected and micro-zones adjacent to them must be pre-cooled to a setback temperature. This helps in preparing the micro-zones for occupancy and quickly achieving setpoint on detecting occupancy. Air

conditioning the micro-zones where occupancy is expected to setpoint temperature leads to energy wastage if the space doesn't get occupied as expected. The optimal setback temperature is about 4°C higher than the set-point temperature. This value can be adjusted and optimized if thermal discomfort is observed. The optimal setback temperature can be 2-6°C higher than setpoint temperature.

b) The time at which setback temperature must be initiated can vary from 2-5 mins based on the rate of cooling in the zone. The rate of cooling depends on the area of the micro-zone, velocity of supply and ambient temperature in the zone.

c) At the time of occupancy, the occupied micro-zones are to be maintained at full flow, while the micro-zones adjacent to them are to be supplied with setback flow. The setback velocity can be about 50% to 70% of planned supply velocity. The velocity can be further optimized considering thermal comfort and energy consumption and the process can be another invention.

    a. The number of micro-zones with setback flow reduces as more micro-zones are occupied. This is because when more micro-zones are air-conditioned, supply air jets attain the required spread because of the attractive force of the air jets in the adjacent micro-zone and this reduces the need of setback flow. Setback flow in each adjacent unoccupied micro-zones is stopped if the occupied micro-zone is near set-point temperature, i.e ±1 °C from setpoint temperature. It must again be started if the temperature difference increases to more than 1°C.

    b. Sometimes setback temperature is required in two layers of micro-zones adjacent to occupied micro-zone to avoid attachment or convergence of air jets. The second layer of adjacency is shown in Figure 2b. In such cases, if setpoint is not achieved in the occupied micro-zone even after maintaining setback flow for few minutes in micro-zones adjacent to the occupied micro-zone (shown in figure 2a), setback flow must be maintained in the micro-zones adjacent

to the micro-zones with setback flow. Thus, two layers of micro-zones adjacent to the occupied micro-zone will have setback flow.

d) When the temperature in an occupied micro-zone is only a few degrees higher (i.e 3-4 °C higher) than the setpoint temperature and if the micro-zone is surrounded by other occupied micro-zones, the airflow in the occupied micro-zone must be reduced to setback flow as thermal coupling from surrounding micro-zones will cool the micro-zone. The flow is stopped, if the micro-zone is near setpoint temperature (i.e., less than 1 °C), as any additional flow will lead to over-cooling.

e) After attaining the setpoint temperature in the occupied micro-zone, other than the ones surrounded by other occupied micro-zones, the airflow in the occupied zone must be reduced to low power maintenance flow. Hence, the thermal conditions in occupied micro-zones are to be monitored frequently (i.e. every 5 mins) to ensure that the PMV values lie between ± 0.5 and draft or thermal gradients are not present. Velocity of setback flow in adjacent diffusers can also be reduced to 50% - 70% of the setback flow in the occupied micro-zone.

f) When several adjacent micro-zones are to be conditioned or the entire zone is to be conditioned, same volumetric flow through all the diffusers leads to excessive merging of air-jets. This is avoided by using 'Alternated Flow' strategy. In this, one diffuser is operated a full velocity while the adjacent diffuser is operated at a low velocity. This helps in increasing the spread of air jets in the micro-zones with diffusers with full flow. After few mins (say 2 mins), the airflow in diffusers with full flow are reduced and the others are increased to full flow. This helps in channelizing cool air to the micro-zones which now has full flow. Thus, the operation is alternated at short intervals (e.g. every 2 mins) until comfortable conditions are attained in all occupied micro-zones. If several (i.e., more than six) adjacent micro-zones are to be air-conditioned, 'Alternated Flow' strategy must be used. The working of alternated flow is illustrated in the Figure 4. In this, the occupied micro-zones shown in red are operated in full flow while the ones the blue are operated in low velocity setback flow. The

micro-zones shown in red are air conditioned through the full flow in the micro-zone and adjacent setback flow. By switching the micro-zones with full flow and setback flow after few mins (about 2 mins) all occupied micro-zones are air-conditioned.

g) While maintaining multiple set-point temperatures in different micro-zones, micro-zones with high setpoint temperatures must be located in the sides or corners to reduce the effect of thermal coupling from other micro-zones with low setpoint temperatures.

Section 2: Systematic method for MZOCC

The aforementioned protocols are linked using a flow diagram. The components of the flow diagram are as given in Figure 5. The two level of protocols are shown in Figure 5. The first level has 4 components. Component A gives guidelines to delineate micro-zonal boundaries within a thermal zone. Two key aspects considered here are (1) the size of micro-zones and spacing between diffusers, and (2) planned occupant location and schedule. Component B give guidelines to plan diffuser arrangement. Partition heights are planned in component C and following the guidelines given in components A to C, best micro-zonal layout is selected in component D.

The second level has 5 components. Component E and F give a method to analyze occupancy conditions to finalize occupancy schedule and setpoint temperature or thermal preference in each micro-zone. Component G gives guidelines to plan airflow control strategies considering real-time occupancy conditions. It checks the indoor temperature, location of occupied micro-zones and thermal comfort in occupied micro-zones to improve airflow through diffusers.

Component H gives guidelines to plan setback conditions in unoccupied micro-zones to reduce thermal discomfort in occupied micro-zones

Component I gives guidelines on when to switch high velocity flow to low velocity setback flow or maintenance flow or stop airflow in occupied micro-zones or adjacent micro-zones.

Detailed scheme of the process

The detailed scheme of the process expanding the working of all the components are given in Figure 6. Protocols 1a to 1f are included in component A. This explains the process of delineating micro-zones in a room. A given zonal layout is divided to core and perimeter zones. The depth of the perimeter can be 4.5m or lie between 3m-6m depending on the incident solar radiation. The selection of size and shape of micro-zones are dictated by the activities in the zone and the area catered by different diffuser types. Table 1 gives the area required for different activities and Table 2 gives the area catered by different diffuser types. These were tabulated from an extensive survey conducted in Indian open-plan offices.

While developing micro-zonal layouts, it is important to control merging, attachment or convergence of air jets. If the spacing between supply diffusers and walls are less than the spread of air jets, the probability of attachment of air jets to the walls are higher and must be avoided. Each micro-zones must also not be less than the spread of air jets to avoid merging of air jets from adjacent diffusers. The micro-zonal layout can be improved considering planned occupancy schedule. If adjacent micro-zones have similar occupancy schedule, thermal preferences, activities and setpoint temperature, the micro-zones are to be merged to form a single micro-zone. Also, if the micro-zonal boundaries cut through occupants in regions of planned occupancy, the furniture layout must be rearranged to ensure that the virtual boundaries do not cut through occupants. Few micro-zonal layouts satisfying the following conditions can be selected to plan diffuser arrangement.

Component B comprises of protocols 1g to 1h. The number of supply diffusers are selected by dividing the area of micro-zone by the area catered by the supply

diffuser. Supply diffusers are placed in the center of the micro-zone. If more than one supply diffuser is present in a micro-zone, they are spaced at a distance equal to the spread of air jets from each supply diffuser. Return diffusers are placed around supply diffusers at distances greater than the spread of air jets. This is done by drawing imaginary circles around supply diffusers of radii equal to the spread of air jets.

1i is included in component C. First a partition height of 60cm from the table is used to check whether the partition blocks cool air from escaping to adjacent zones. If yes, the partition height is lowered until the optimal partition height where cool air is restricted is obtained.

The micro-zonal layout with diffuser arrangement, furniture arrangement and partition heights are finalized in component D

In the second level of protocols, components E and F evaluates the occupancy conditions and plans the setpoint temperature in each micro-zone. This is done considering two scenarios. The first scenario is where occupants do not have a fixed seat and can be grouped based on their thermal preferences. The setpoint temperature in each micro-zone is set according to the group thermal preference in the micro-zone. The second scenario is where occupants have fixed seats and a fixed setpoint temperature is used in all micro-zones. It is to be noted that these two scenarios are the two extreme cases, there can be other scenarios such as occupants having fixed seats but the setpoint temperature in each micro-zone is different or occupants are grouped only based on thermal preference and not based on occupancy schedule. These can be obtained by modifying the extreme scenarios and is hence not repeated.

Component G details the working of OCC. This has two parts. G1 checks the occupancy conditions within micro-zones for a given time-frame. This can be taken as per context based on the frequency of change in occupancy. It can be 30 mins or can be between 15 mins to 1 hour. As per the protocols, if several

adjacent micro-zones are occupied, alternated flow (AF) strategy must be used to avoid unwanted merging of air jets. This strategy is used only when the temperature difference between the occupied micro-zones and setpoint temperature are comparable, i.e greater than 4°C. Once the setpoint temperature is achieved, the airflow in all diffusers in the occupied micro-zones can be reduced to maintenance flow as mentioned in protocols 2e. The flow rate in maintenance flow is calculated using Equation 6.

Further, setback temperature must be maintained in the micro-zones where occupancy is expected and in micro-zones adjacent to the expected micro-zones. Hence, expected occupancy must be evaluated using an occupant behavior model developed for the zone considering typical occupancy schedules and setback temperature must be maintained few mins (about 5 to 10 mins) prior to occupancy. This is given in component G1 of the flow diagram and in protocols 2a.

Component G2 checks for thermal discomfort due to horizontal thermal gradients. If the air temperature at the micro-zonal boundary is 2°C less than that at the center of the micro-zone, it indicates that cool air from adjacent diffusers are merging and moving away from the occupied region. In this case, setback flow or setback temperature needs to be maintained in adjacent micro-zones to avoid such discomfort.

Component H gives the details on planning airflow in occupied and unoccupied micro-zones.

While thermal comfort is not achieved in the occupied micro-zone, if the micro-zone is between other occupied micro-zones and the difference in air temperature in the micro-zone and setpoint temperature lie between 1°C to 4°C, the diffusers in the micro-zone must operate in setback flow. If the difference in temperature is greater than 4°C, the diffusers must operate in full flow and if the difference in temperature is less than 1°C, airflow through the diffusers in the micro-zone must be stopped.

If the micro-zone is a first layer adjacent micro-zone (condition of first level of adjacency was defined in Figure 2a), setback flow is maintained in the micro-zone until setpoint temperature is attained in the occupied micro-zone. The setback flow can be 50% – 70% of the flow in the occupied micro-zone. If the micro-zone is a second layer of adjacent micro-zone as shown in Figure 2b, setback temperature is to be maintained in the micro-zone, if setpoint temperature is not attained in the occupied micro-zone after a specific period (say 5 mins) of air conditioning.

Component I gives the details of reducing airflow to maintenance flow or stopping the flow. If setpoint temperature is attained in the occupied micro-zones, thermal comfort conditions can be evaluated before reducing the airflow. First, thermal gradients are evaluated to ensure that air jets do not converge below the diffuser and setback flow or setback temperature are used in adjacent micro-zones to avoid convergence. Second, the percentage of people dissatisfied due to draft is evaluated using Equation 7. If these conditions are met, the airflow in the occupied micro-zones are reduced to maintenance flow.

Working example

The office chosen is located in Hyderabad, India, in a hot and dry climate and houses 60 employees. The furniture and HVAC layout of the open-plan office is shown in Figure 7a and the interior views are shown in Figure 7b

The open-plan office has workstations in the central area, activity-based work (ABW) spaces and informal discussion spaces in the east side and a break room in the west. An enclosed formal meeting area is located at the centre of the office. The open plan area of the office is air-conditioned using 42 HP VRF outdoor unit, 22 TR package unit and 11 TR ceiling suspended unit. The meeting room is equipped with two cassette ACs. The open-plan office has ducted air distribution system with a mix of side and ceiling throw. But side throws are not

suitable for MZOCC. Hence to analyze MZOCC, it is assumed that the zone is conditioned using four-way square ceiling diffusers. The occupancy behavior is collected through an online survey on the general office usage of occupants.

With the assumption that square ceiling diffusers are used for air distribution, seven zoning layouts are developed as shown in Figure 8. Layouts f and g correspond to the protocols while others do not.

Zoning type 'a' is similar to the HVAC zoning currently existing in the studied office space as shown in Figure 7a , with four-way square ceiling diffusers used instead of rectangular grills and is hence not repeated in Figure 8. In this, the entire open-plan office is divided into two thermal zones. Since two AHUs are used, it is assumed that two occupant sensing mechanisms, two thermostats and two OCC controllers are installed in the zone. The meeting room, which is separated by physical partitions, is zoned separately. Since the open-plan office has no external walls, core-perimeter zoning is not considered.

Zoning type 'b' divides each activity space in the open-plan office into different micro-zones. The occupancy schedule and thermal preferences for each activity space is different and hence must be virtually separated. Thus, the open-plan office is divided into 12 micro-zones. A setback temperature of 26°C is assumed for the corridors. Zoning type 'c' further divides functional micro-zones using grids drawn along the circulation paths between workstations following protocol 1b. The size of each micro-zone is 6m x 6m. In zoning type 'd', the functional micro-zones are further divided by drawing virtual boundaries through the tables in the space. The size of each micro-zone is 3m x 6m. Under this division, two square ceiling diffusers is present in each micro-zone considering the spread of air-jets. In zoning type 'e', the micro-grids are further divided such that only one square ceiling diffuser will be present in each micro-zone. Considering the area catered by a 4-way square ceiling diffuser of size 45x45cm, the micro-zone is sized 3x3m. This corresponds well to protocol 1c, where the size of micro-zone is planned using Tables 1 and 2. Further division of micro-zone can lead to merging of air jets from adjacent diffusers when operated simultaneously. But it is

observed that in a few micro-zones, the distance between supply diffusers and wall is less than 1.5m. From the discussion on protocols, it is known that this will lead to clinging of cool air to the walls.

To avoid clinging of air jets, a larger rectangular grid is considered for these spaces as shown in case 'f'. Further, the unoccupied corners of the micro-zones need not be conditioned. Hence, in zoning type 'g', the shape of the micro-zone is altered to an octagon of side 3m. This makes the micro-zone more compact while serving larger occupancy and hence reduces the maximum airflow required by the diffuser. The total number of diffusers needed is also reduced compared to 3x3m grid based micro-zoning, but considering the larger area to be catered, square ceiling diffusers of side 60cm x 60cm are to be used. This is done by assuming similar planned occupancy in the workspaces following protocol 1e.

Layouts 'f' and 'g' corresponds to the protocols better than others. These layouts were generated under the assumption that furniture layout cannot be altered. But in layout 'f', micro-zonal boundaries cut through occupants. Following protocol 1d, a new layout 'h' is developed by altering the furniture layout and conforming to all protocols for micro-zoning.

Following the protocols for diffuser arrangement and partition heights, layout 'h' with rectangular shaped return diffusers placed outside the radius of the spread of air jets is selected. The partition heights are selected as 60cm. Thus, the first level of protocols helps in planning optimal micro-zonal layouts, diffuser arrangement and partition heights. The selected layout is shown in Figure 9.

Evaluation of energy savings

Occupancy scenario 1 with setpoint temperature of 23°C in all micro-zones.

The location of 60 occupants within the micro-zones are shown in Figure 9. The micro-zones are numbered MZ1 to MZ24 as shown in Figure 9. The occupancy condition in the zone is updated every 30 mins and the airflow control is also

adjusted accordingly. A set-point temperature of 23°C is assumed for all the micro-zones. The results of air distribution and thermal contours for every 30 mins is shown in Figure 10. The micro-zones occupied at each time interval are also highlighted in Figure 10. Diffusers highlighted in dark blue has full flow and diffusers in light blue have setback flow.

Occupants start occupying the office from 8:30 am. As per the protocols, prior to occupancy, a setback temperature is to be maintained in the region where occupancy is expected and the spaces around it. Twelve micro-zones as shown in Figure 10 are air-conditioned to a setback temperature of 27°C five mins prior to occupancy. On initiating cooling, it takes about 2 mins to reach setback temperature. At 8:30 am, the diffusers in the occupied micro-zones are operated at its planned volumetric flow with a velocity of 0.45m/s, whereas a setback flow of 0.3m/s is supplied through the diffusers in the adjacent micro-zones. These flow velocities are the optimized supply velocities. The diffusers with full flow and diffusers with setback flow are separately marked in Figure 10.

Following the protocols, MZOCC tries to attain setback temperature a few minutes before occupancy and setback flow is maintained in the micro-zones adjacent to the occupied micro-zone at the time of occupancy. The airflow control is evaluated every 30 mins considering the changes in occupancy. Following the details given in component H, the Indoor temperature is evaluated every 5 mins to check whether setpoint temperature is achieved or thermal discomfort is observed following the details given in component I. On attaining set-point temperature, the airflow in the occupied micro-zone is reduced to setback flow as only limited airflow is required to maintain cooling. Velocity of setback flow in adjacent diffusers must also be reduced to 50% - 70% of the setback flow in the occupied micro-zone following the protocol of flow in adjacent diffusers must always be 50% - 70% of the flow in the occupied micro-zone.

The analysis is performed from 8:00 am to 10:30 pm. The energy required to air-condition the entire zone is estimated for this period. The Equations used to estimate energy consumption for every 30 mins is given below:

The energy consumed is evaluated considering the energy required attain thermal comfort and energy required to maintain thermal comfort using Equation-1

$$E_{Total} = E_{cooling\ down} * T_{cool\ down} + E_{maintenance} * T_{operation-cool\ down} \quad \textbf{Equation 1}$$

Where,

E_{Total} - energy consumed (kWh)

$E_{cooling\ down}$ - power for reaching setpoint temperature (kW)

$T_{cool\ down}$ - cooling time (s)

$E_{maintenance}$ - power for maintaining setpoint temperature (kW)

$T_{operation}$ - duration for which AC is operated (s)

Power consumed at an instance during cool down and maintenance is computed separately as the sum

$$E = E_{cooling} + E_{fan} \quad \textbf{Equation 2}$$

Power for reaching setpoint is computed using Equation 3, where enthalpy values are obtained from the psychometric chart and fan power is calculated using Equation 4

$$E_{cooling} = Q * (h_r - h_s) \quad \textbf{Equation 3}$$

$$E_{fan} = \frac{(\gamma Q * \Delta p)}{3600 * 1000 * \eta} \quad \textbf{Equation 4}$$

Where,

Q - volumetric flow rate (m3/s)

γ - specific weight of air (taken as 2.09N/m3 for 13°C)

h_r - the enthalpy of unconditioned air (return air + outdoor air for ventilation) (kJ/kg)

h_s - the enthalpy of supply air (kJ/kg)

Δp -total fan pressure (assume 750 Pa)

η -efficiency of the fan (assume 70%)

Ventilation rates are computed as per ASHRAE 62.1 (Hedrick et al., 2013) using Equation 5.

$$Q_{outdoor} = R_p * P + T_a * A_{zone}$$ **Equation 5**

Where,

R_p - volumetric flow required per person (5 for office spaces)

P - number of people

T_a - ventilation to remove toxic gases (0.06 for office spaces)

A_{zone} - area of the occupied micro-zones

Mass-flow rate of air required to remove heat generated in the space while maintaining cooling is computed as given in Equation 6 following ASHRAE standards.

$$m_s = \left(\frac{Q_{sr}}{C_{pm}(t_i - t_s)}\right)$$ **Equation 6**

Where,

m_s - mass flow rate

Q_{sr} - heat generated

C_{pm} -humid specific heat of moist air = 1.0216 kJ/kg dry air. K

t_i -indoor temperature

t_s -supply air temperature .

m_s is converted to Q by dividing with the mass of air. This flow comprises of outdoor air and return air mixed as per ventilation requirements obtained from Equation 5.

The percentage of people dissatisfied due to draft is calculate using Equation 7

$$PD = (34 - Ta)\,(V - 0.05)^{0.62}\;(0.37\,V\,Tu + 3.14) \qquad \textbf{Equation 7}$$

PD – the percentage of people dissatisfied due to draft

V - velocity

Ta – air temperature

Tu – Turbulence intensity

The energy required for such zonal conditioning is 1485 kWh. The energy consumed under MZOCC is estimated by adding the energy consumed every 30 mins following the airflow control strategy shown in in Figure 10. Table 3 gives the details of the energy consumed for every 30 mins and the overall energy saved compared to full zone conditioning. About 60% energy is saved using MZOCC compared to full-zone air conditioning.

Table 3: Energy consumed on a typical day

Time	Time to cool s	Cooling power kw	cooling energy kwh	Maintenance power kw	Maintenance Energy kwh	Energy (every 30 mins) Kwh
08:00:00	0	0.00	0.00	0.00	0.00	0.00
08:25:00	100	12.00	0.33	0.00	0.00	0.33
08:30:00	250	600.21	41.68	1.68	0.73	42.41
09:00:00	200	886.03	49.22	2.22	0.99	50.21
09:30:00	200	1314.75	73.04	5.42	2.41	75.45
10:00:00	200	1171.85	65.10	7.02	3.12	68.22
10:30:00	150	1028.94	42.87	5.95	2.73	45.60
11:00:00	150	1200.43	50.02	5.42	2.48	52.50
11:30:00	100	1200.43	33.35	8.09	3.82	37.16
12:00:00	0	0.00	0.00	8.09	3.82	3.82
12:30:00	0	0.00	0.00	8.09	3.82	3.82
13:00:00	100	657.38	18.26	6.49	3.06	21.32
13:30:00	100	571.63	15.88	5.42	2.56	18.44
14:00:00	100	285.82	7.94	7.02	3.31	11.25
14:30:00	100	457.31	12.70	7.55	3.57	16.27

15:00:00	100	457.31	12.70	7.02	3.31	16.02
15:30:00	100	457.31	12.70	7.02	3.31	16.02
16:00:00	60	571.63	9.53	8.09	3.91	13.44
16:30:00	60	514.47	8.57	7.55	3.65	12.23
17:00:00	60	514.47	8.57	7.02	3.39	11.97
17:30:00	60	342.98	5.72	6.49	3.14	8.85
18:00:00	40	285.82	3.18	4.35	2.13	5.30
18:30:00	40	228.65	2.54	4.35	2.13	4.67
19:00:00	30	400.14	3.33	6.49	3.19	6.52
19:30:00	30	400.14	3.33	6.49	3.19	6.52
20:00:00	30	400.14	3.33	5.95	2.93	6.26
20:30:00	30	342.98	2.86	6.49	3.19	6.05
21:00:00	30	342.98	2.86	5.42	2.66	5.52
21:30:00	30	285.82	2.38	3.29	1.62	4.00
22:00:00	0	0.00	0.00	0.00	1.62	1.62
22:30:00	0	0.00	0.00	0.00	1.62	1.62
					Total	**573.07**
Full zone	900	5659.156971	1414.789243	8.086738011	70.53432599	1485.32
					Savings	**61.42%**

Occupancy scenario 2 with different setpoints in each micro-zone.

Here, it is assumed that occupants with similar thermal preferences are grouped to allot them to micro-zones and each micro-zone has its own setpoint temperature. The setpoint for each micro-zone is as given in table 4. The occupancy pattern is assumed to be different from the previous case in such a way that more occupants are present in each micro-zone and fewer micro-zones are occupied for a given time-frame. The micro-zones occupied every 30 mins are highlighted in Figure 11.

Table 4: setpoint temperature in each micro-zone

Micro-zone no.	Set-point temperature (°C)
MZ1	27
MZ2	27
MZ3	27
MZ4	26
MZ5	27
MZ6	27
MZ7	21
MZ8	20
MZ9	21
MZ10	21
MZ11	22
MZ12	24
MZ13	20
MZ14	23
MZ15	25

The thermal contours every 30 mins are given in Figure 11.

As the set-point is different in each micro-zone, micro-zones that have higher set-point temperature requires very less amount of direct cooling. Following the details given in component H, thermal coupling and set-back flow from adjacent micro-zones help in attaining this high set-point temperature.

The space is occupied from 9:00 am and occupants are present only in the southern part of the zone. Hence set-back temperature is maintained only in the southern part. At 9:00 am MZ7, MZ8 and MZ13 are occupied. As MZ7 and MZ8 are adjacent to each other with same occupancy schedule and temperature preference they are merged and considered as a single micro-zone following protocol 1e. Setback flow is provided in micro-zones around MZ13 to avoid concentration of cool air below the diffuser following the details given in component I.

At 9:30 am, MZ9, MZ11 and MZ15 are also occupied. But they have different temperature set-points and are hence not merged. While trying to maintain a very low temperature of 20°C, it is seen that cool air concentrates in the center portion of the micro-zone. This cool air travels to the adjacent micro-zone below the breathing level causing discomfort due to vertical thermal gradients. Hence, it is difficult to maintain very low temperature setpoints using MZOCC. This is observed in case of 11:30 am in MZ13 in Figure 11. High set-point temperatures are preferred in corner or side micro-zones with corridors or unoccupied activity spaces in the side. This helps in reducing the cooling effect due to thermal coupling from adjacent micro-zones with low set-points. This also corresponds to protocol 2g. In the case study, protocol 2g was not followed and hence thermal discomfort is observed. As the space is only occupied from 9:00 am, the energy required for full zone conditioning reduces to 1477 kWh and the total energy required under MZOCC under the given occupancy and temperature set-point conditions is 316 kWh. Thus, 78.6% of energy is saved. The energy consumed for every 30 mins is given in Table 5.

In few scenarios, switching off setback conditions in few micro-zones helps in reducing unwanted merging and attachment of air jets. Hence, though the protocols are effective in handling most of the situations, few exceptions are also observed and the airflow must be altered to avoid unwanted deflection of air jets.

Table 5: Energy consumed when occupants are grouped based on occupancy schedule and thermal preferences

Time	Cooling power kw	cooling energy kwh	Maintenance power kw	Maintenance Energy kwh	Energy (30 mins) kwh
08:00:00					
08:30:00					
08:55:00	7.72	0.21	0.00	0.00	0.21
09:00:00	371.56	20.64	1.68	0.75	21.39
09:30:00	685.96	38.11	3.29	1.46	39.57

10:00:00	457.31	25.41	3.29	1.46	26.87
10:30:00	657.38	27.39	3.82	1.75	29.14
11:00:00	657.38	27.39	3.82	1.75	29.14
11:30:00	371.56	10.32	1.68	0.80	11.12
12:00:00	685.96	19.05	3.82	1.80	20.86
12:30:00	600.21	16.67	3.82	1.89	18.56
13:00:00	257.23	7.15	1.68	0.83	7.98
13:30:00	228.65	6.35	5.11	2.41	8.76
14:00:00	228.65	6.35	2.22	1.05	7.40
14:30:00	571.63	15.88	4.35	2.06	17.93
15:00:00	400.14	11.12	3.82	1.80	12.92
15:30:00	285.82	7.94	3.29	1.55	9.49
16:00:00	371.56	6.19	3.29	1.59	7.78
16:30:00	171.49	2.86	5.11	2.47	5.33
17:00:00	171.49	2.86	5.11	2.47	5.33
17:30:00	228.65	6.35	5.11	2.41	8.76
18:00:00	171.49	4.76	1.68	0.80	5.56
18:30:00	57.16	1.75	0.70	0.33	2.08
19:00:00	114.33	2.22	0.70	0.34	2.56
19:30:00	171.49	5.72	1.68	0.79	6.50
20:00:00	114.33	2.54	1.68	0.80	3.35
20:30:00	114.33	2.22	1.68	0.81	3.03
21:00:00	57.16	0.95	0.70	0.34	1.29
21:30:00	57.16	0.48	0.70	0.35	0.82
22:00:00	57.16	0.64	0.70	0.34	0.98
22:30:00	114.33	0.95	1.40	0.69	1.64
				Total	**316.35**
Full zone	5659.156971	1414.789243	8.086738011	62.44758797	1477.24
				Energy savings	**78.58%**

Thus, it is proven that MZOCC planned using the protocols can reduce 60% to 80% energy consumption based on the occupancy conditions and temperature setpoints in the zone.

The protocols act as a guide to help architects, HVAC engineers and building managers to plan and operate Micro-Zonal Occupant-Centric Control (MZOCC).

Advantages of the described invention:

1. Currently, standard room-level OCC is being used within rooms to locally air-condition the occupied regions to reduce HVAC energy consumption. But this causes discomfort to occupants as strategies to control air movement through the virtual boundaries are not considered. The present invention, gives a set of guidelines to be followed to avoid uncontrolled inter-micro-zonal interaction through the virtual boundaries. The first level of the protocols gives a method to plan micro-zonal layouts in any given room. The second level of protocols gives a method to plan airflow control in the occupied micro-zones as well as unoccupied micro-zones to achieve setpoint temperature or thermal comfort around occupants at minimum energy consumption.

2. The protocols helps to reduce the need to conduct CFD simulations to plan real-time changes in airflow control through the diffusers. Extensive CFD simulations have already been conducted to formulate the protocols.

CLAIMS:

1. A process to implement and control localized air-conditioning of occupied regions in large confined space to reduce HVAC energy consumption comprising

delineating the space into multiple micro-zones based on a first level of protocol and static parameters thereof including planned activities, occupancy patterns, diffuser characteristics, and furniture layout;

controlling airflow through diffusers in the occupied and unoccupied micro-zones to achieve setpoint temperature or thermal comfort only in the occupied regions using minimum HVAC energy through implementing a second level of protocol with dynamic parameters relating to the micro-zones including real-time occupancy, thermal comfort preferences, ambient conditions, and inter-micro-zonal thermal interactions.

2. The process as claimed in claim 1, wherein step of controlling airflow through diffusers in the occupied and unoccupied micro-zones includes

detecting occupancy within one or more of the micro-zones using environment sensors;

involving diffusers and selectively controlling such diffusers for anyone or more of providing full airflow to occupied micro-zones, setback airflow to first and optionally second layer of adjacent unoccupied micro-zones, and stopping airflow in other unoccupied micro-zones;

monitoring temperature gradients and occupant comfort conditions through sensors within each occupied micro-zone and accordingly adjusting the airflow to a maintenance level in occupied micro-zones once setpoint temperature is achieved;

selectively alternating full and setback airflow among adjacent micro-zones in cases where multiple micro-zones are simultaneously occupied, to minimize jet convergence and reduce HVAC energy consumption.

3. The process as claimed in claim 1 or 2, wherein the delineating the space into multiple micro-zones includes micro-zoning the confined space which is preferably an open-plan indoor environment by separating its externally heated core and internally heated perimeter following standard core-perimeter zoning strategy ensuring space is divided into a number of micro-zones according to planned activities and the micro-zones are forming a grid with size chosen based on area required for different activities.

4. The process as claimed in claims 1 to 3, wherein the diffusers are selected based on the grid size and also the grid size can also be adjusted considering the area that can be catered by individual diffusers and the minimum distance between diffusers considering the spread of air jets;

wherein, if the size of each micro-zone corresponds to the standard spread of air jets from the selected diffusers, one supply diffuser is to be provided for each micro-zone, otherwise number of diffusers is obtained by dividing the area of the micro-zone with the area catered by a single diffuser considering the standard spread of air-jets and rounding off to the next highest whole number.
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5. The process as claimed in claims 1 to 4, wherein furniture arrangement in the confined space is re-organized such that micro-zonal boundaries do not cut through occupants.

6. The process as claimed in claims 1 to 5, wherein the micro-zones are defined to ensure that inter micro-zonal boundaries avoids overlapping with planned occupant positions or seating in the space as per the first level of protocol and the static parameters, whereby adjacent micro-zones with similar activity, occupancy schedule and thermal comfort preferences or setpoint temperature is merged to a single micro-zone.

7. The process as claimed in claims 1 to 6, wherein positions of return diffusers are determined by involving drawing imaginary circles of radii equal to the standard spread of air-jets around the supply diffusers and placing the return diffusers outside or at the boundary of the imaginary circle, such as that the air jets will try to move towards the return diffusers and hence the location of return diffusers define the shape of the region with cool air in the micro-zone.

8. The process as claimed in claims 1 to 7, wherein when several adjacent micro-zones are to be conditioned or the entire zone is to be conditioned, same volumetric flow through all the diffusers and related excessive merging of air-jets is avoided by using 'Alternated Flow' strategy, whereby, one diffuser is operated a full velocity while the adjacent diffuser is operated at a low velocity for increasing the spread of air jets in the micro-zones with diffusers with full flow and after few mins, the airflow in diffusers with full flow are reduced and the others are increased to full flow for channelizing cool air to the micro-zones which now has full flow and the alternate flow is repeated until comfortable conditions are attained in all occupied micro-zones.

9. The process as claimed in claims 1 to 8, wherein thermal comfort is continuously evaluated using Predicted Mean Vote (PMV) values and draft prediction models to determine if maintenance flow is sufficient.

10. The process as claimed in claims 1 to 9, wherein expected occupancy is predicted using a data-driven occupancy behavior model.

11. A system to implement and control localized air-conditioning of occupied regions in large confined space to reduce HVAC energy consumption comprising
a micro-zonal layout module configured to divide indoor environment of the large confined space into multiple micro-zones;

a set of supply and return air diffusers positioned within said micro-zones, wherein each supply diffuser is associated with at least one return diffuser placed based on the spread of air jets to control airflow patterns;

a control unit configured to execute bi-level control protocols involving

(i) a first level of protocols for determining optimal micro-zonal layouts based on static parameters including diffuser spread, thermal loads, activity areas, and inter-zonal interactions and accordingly driving the micro-zonal layout module; and

(ii) a second level of protocols for dynamically controlling airflow within each micro-zone by controlling the set of supply and return air diffusers based on real-time occupancy, predicted occupancy, temperature readings, and thermal comfort preferences targeting minimization of HVAC energy consumption by selectively adjusting airflow in occupied and unoccupied micro-zones using strategies including setback flow, full flow, alternated flow, and maintenance flow.

12. The system as claimed in claim 11, includes environmental sensors including at least three vertically spaced temperature sensors per micro-zone to monitor temperature, velocity, and humidity at multiple heights.

13. The system as claimed in clams 10 or 11, wherein the return diffusers are positioned outside or at boundary of imaginary circle of radii equal to standard spread of air-jets around the corresponding supply diffusers such as that air jets will try to move towards the return diffusers and hence the location of return diffusers define the shape of the region with cool air in the micro-zone.

14. The system as claimed in claims 10 to 13, wherein the control unit receives occupancy information within one or more of the micro-zones from the environment sensors and accordingly sets the supply air diffusers (i) at full airflow to occupied micro-zones, setback airflow to first and optionally second layer of adjacent unoccupied micro-zones, and stop airflow in other unoccupied micro-zones;

wherein said control unit further monitors temperature gradients and occupant comfort conditions through the sensors within each occupied micro-zone and accordingly adjusts the sets the supply air diffusers for an airflow to a maintenance level in the occupied micro-zones once setpoint temperature is achieved including selectively alternating full and setback airflow among adjacent micro-zones in cases where multiple micro-zones are simultaneously occupied, to minimize jet convergence and reduce HVAC energy consumption.

15. The system as claimed in claims 10 to 14, wherein when several adjacent micro-zones are to be conditioned or the entire zone is to be conditioned, the control unit sets one supply diffuser at a full velocity while the adjacent supply diffuser is operated at a low velocity for increasing the spread of air jets in the micro-zones with diffuser with full flow and after few mins, the control unit reduces airflow in that diffuser with full flow and set the other diffuser at full flow for channelizing cool air to the micro-zones which now has full flow, whereby the

control unit repeats the alternate flow until comfortable conditions are attained in all occupied micro-zones.

16. The system as claimed in claims 10 to 15, wherein the micro-zonal layout module set the micro zones based on area that can be catered by individual diffusers, minimum distance between diffusers considering the spread of air jets and inter micro-zonal boundaries avoids overlapping with planned occupant positions or seating in the space as per the first level of protocol and the static parameters, whereby adjacent micro-zones with similar activity, occupancy schedule and thermal comfort preferences or setpoint temperature is merged to a single micro-zone.