

METHOD AND SYSTEM FOR SCHEDULING A HEATING, VENTILATION AND AIR-CONDITIONING SYSTEM

TECHNICAL FIELD

- 5 [0001] Various aspects relate to a method and a system for scheduling a heating, ventilation and air-conditioning (HVAC) system.

BACKGROUND

- [0001] Buildings consume significant energy and the Heating, Ventilation and Air-
10 Conditioning (HVAC) systems contribute to significant proportion of such consumption. Commercial HVAC systems are either Variable Air Volume (VAV) or Variable Refrigerant Volume (VRV)-type systems supplying cooling energy to multiple zones. The controllers for such systems can vary from being a simple thermostat to an optimization-based controller (e.g., Model Predictive Control (MPC)). Many HVAC control methods have a
15 centralized architecture and aim to minimize energy consumption across all zones using MPC due to its ability to handle complicated constraints, nonlinear dynamics, and physical behaviors. However, due to computational difficulties with a large number of zones and implementation issues centralized control architecture is unsuitable due to computation complexity.

- 20 [0002] A need exists to provide an improved method and system for scheduling a HVAC system.

SUMMARY

- [0003] According to a first aspect of the present disclosure, a method for scheduling a
25 heating, ventilation and air-conditioning (HVAC) system is provided. The HVAC system

may include an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, and the at least one AHU is configured to serve a plurality of zones. The method may include: obtaining zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for the plurality of zones, 5 the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points; obtaining conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air; and determining, for the at least one AHU and for a prediction horizon, a minimum 10 conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-points for the plurality of zones.

[0004] According to a second aspect of the present disclosure, a system for scheduling 15 a heating, ventilation and air-conditioning (HVAC) system is provided. The HVAC system may include an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, the at least one AHU is configured to serve a plurality of zones. The system may include: a zone module configured to obtain zone environmental information including a zone temperature, a zone air quality indicator and zone set-points 20 for the plurality of zones, the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points; an input module configured to obtain conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air; and a scheduler, for 25 the at least one AHU and for a prediction horizon, configured to determine a minimum

conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-points for the plurality of zones.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Throughout the drawings, it should be noted that like reference numbers are used to depict the same or similar elements, features, and structures. The drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating aspects of the disclosure. In the following description, some aspects of the disclosure are described with reference to the following drawings, in which:

FIG. 1 is a flow chart showing an example method for scheduling a heating, ventilation and air-conditioning (HVAC) system, according to various embodiments of the present disclosure;

15 FIG. 2 is a block diagram showing an example system for scheduling a HVAC system, according to various embodiments of the present disclosure;

FIG. 3 is a block diagram showing an example HVAC system, according to various embodiments of the present disclosure;

FIG. 4 is a block diagram showing an example method for scheduling a HVAC system, according to various embodiments of the present disclosure;

20 FIG. 5 is a block diagram showing a multi-layer neural network used in an example method for scheduling a HVAC system, according to various embodiments of the present disclosure;

FIG. 6 depicts an upper graph showing a comparison of actual and estimated temperatures with an example model for scheduling a HVAC system and a lower graph showing errors

between the actual and estimated temperatures, according to various embodiments of the present disclosure;

FIG. 7 is a graph showing a comparison of measured and estimated values of CO₂ concentration with an example model for scheduling a HVAC system, according to various
5 embodiments of the present disclosure;

FIG. 8 is a graph showing experimental results, according to various embodiments of the present disclosure; and

FIG. 9 is a block diagram showing an example electronic device, according to an implementation of the present disclosure.

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DETAILED DESCRIPTION

[0006] The following detailed description refers to the accompanying drawings that show, by way of illustration, specific details and aspects in which the disclosure may be practiced. One or more aspects are described in sufficient detail to enable those skilled in the art to
15 practice the disclosure. Other aspects may be utilized and structural, logical, and/or electrical changes may be made without departing from the scope of the disclosure. The various aspects of the disclosure are not necessarily mutually exclusive, as some aspects can be combined with one or more other aspects to form new aspects or embodiments. Various aspects are described in connection with methods and various aspects are described in
20 connection with devices. However, it may be understood that aspects described in connection with methods may similarly apply to the devices, and vice versa.

[0007] It should be understood that the singular terms "a", "an", and "the" include plural references unless context clearly indicates otherwise. Similarly, the word "or" is intended to include "and" unless the context clearly indicates otherwise.

[0008] It will be further understood that the terms “comprise” (and any form of comprise, such as “comprises” and “comprising”), “have” (and any form of have, such as “has” and “having”), “include” (and any form of include, such as “includes” and “including”), and “contain” (and any form of contain, such as “contains” and “containing”) are open-ended linking verbs. As a result, a method or device that “comprises,” “has,” “includes” or “contains” one or more steps or elements possesses those one or more steps or elements, but is not limited to possessing only those one or more steps or elements. Likewise, a step of a method or an element of a device that “comprises,” “has,” “includes” or “contains” one or more features possesses those one or more features, but is not limited to possessing only those one or more features. Furthermore, a device or structure that is configured in a certain way is configured in at least that way, but may also be configured in ways that are not listed.

[0009] Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as “about,” “substantially”, is not limited to the precise value specified but within tolerances that are acceptable for operation of the embodiment for an application for which it is intended. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value.

[0010] As used herein, the phrase of the form of “at least one of A or B” may include A or B or both A and B. Correspondingly, the phrase of the form of “at least one of A or B or C”, or including further listed items, may include any and all combinations of one or more of the associated listed items.

[0011] The term “exemplary” may be used herein to mean “serving as an example, instance, or illustration”. Any aspect or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects or designs.

[0012] The terms “at least one” and “one or more” may be understood to include a numerical
5 quantity greater than or equal to one (e.g., one, two, three, four, [...], etc.). The term “a plurality” may be understood to include a numerical quantity greater than or equal to two (e.g., two, three, four, five, [...], etc.). The phrase “at least one of” with regard to a group of elements may be used herein to mean at least one element from the group consisting of the elements. For example, the phrase “at least one of” with regard to a group of elements may
10 be used herein to mean a selection of: one of the listed elements, a plurality of one of the listed elements, a plurality of individual listed elements, or a plurality of a multiple of listed elements.

[0013] The words “plural” and “multiple” in the description and in the claims expressly refer to a quantity greater than one. Accordingly, any phrases explicitly invoking the
15 aforementioned words (e.g., “a plurality of (objects)”, “multiple (objects)”) referring to a quantity of objects expressly refer to more than one of the said objects. The terms “group (of)”, “set (of)”, “collection (of)”, “series (of)”, “sequence (of)”, “grouping (of)”, etc., and the like in the description and in the claims, if any, refer to a quantity equal to or greater than one, i.e. one or more.

[0014] The term “data” as used herein may be understood to include information in any
20 suitable analog or digital form, e.g., provided as a file, a portion of a file, a set of files, a signal or stream, a portion of a signal or stream, a set of signals or streams, and the like. Further, the term “data” may also be used to mean a reference to information, e.g., in form of a pointer. The term “data”, however, is not limited to the aforementioned examples and
25 may take various forms and represent any information as understood in the art. Any type of

information, as described herein, may be handled for example via one or more processors in a suitable way, e.g. as data.

[0015] The terms “processor” or “scheduler” or “controller” as, for example, used herein may be understood as any kind of entity that allows handling data. The data may be handled according to one or more specific functions executed by the processor or scheduler or controller. Further, a processor or scheduler or controller as used herein may be understood as any kind of circuit, e.g., any kind of analog or digital circuit. A processor or scheduler or controller may thus be or include an analog circuit, digital circuit, mixed-signal circuit, logic circuit, processor, microprocessor, Central Processing Unit (CPU), Graphics Processing Unit (GPU), Digital Signal Processor (DSP), Field Programmable Gate Array (FPGA), integrated circuit, Application Specific Integrated Circuit (ASIC), etc., or any combination thereof. Any other kind of implementation of the respective functions, which will be described below in further detail, may also be understood as a processor, scheduler, controller, or logic circuit. It is understood that any two (or more) of the processors, schedulers, controllers, or logic circuits detailed herein may be realized as a single entity with equivalent functionality or the like, and conversely that any single processor, scheduler, controller, or logic circuit detailed herein may be realized as two (or more) separate entities with equivalent functionality or the like.

[0016] The term “memory” detailed herein may be understood to include any suitable type of memory or memory device, e.g., a hard disk drive (HDD), a solid-state drive (SSD), a flash memory, etc.

[0017] The term “module” detailed herein refers to, or forms part of, or includes an Application Specific Integrated Circuit (ASIC); an electronic circuit; a combinational logic circuit; a field programmable gate array (FPGA); a processor (shared, dedicated, or group) that executes code; other suitable hardware components that provide the described

functionality; or a combination of some or all of the above, such as in a system-on-chip. The term module may include memory (shared, dedicated, or group) that stores code executed by the processor.

[0018] Differences between software and hardware implemented data handling may blur.

- 5 A processor, scheduler, controller, and/or circuit detailed herein may be implemented in software, hardware, and/or as a hybrid implementation including software and hardware.

[0019] The term “system” (e.g., a transaction facilitator system, a computing system, etc.) detailed herein may be understood as a set of interacting elements, wherein the elements can be, by way of example and not of limitation, one or more mechanical components, one or
10 more electrical components, one or more instructions (e.g., encoded in storage media), and/or one or more processors, and the like.

[0020] The term “first”, “second”, “third” detailed herein are used to distinguish one element from another similar element and may not necessarily denote order or relative importance, unless otherwise stated. For example, a first transaction data, a second
15 transaction data may be used to distinguish two transactions based on two different foreign currency exchange.

[0021] Various embodiments of the present disclosure provide a method and a system for scheduling a heating, ventilation and air-conditioning (HVAC) system associated with a building, and more particularly, for optimizing a plurality of building performance
20 parameters in providing an environment (e.g., a desired indoor environment) with respect to a zone of the building. It will be appreciated by a person skilled in the art that the above-mentioned zone may refer to any one or more regions or enclosures or enclosed areas within a building, such as but not limited to, a room (e.g., an office room, a meeting room, an apartment room, a hotel room and so on), an open-plan office space, a lecture hall, a theatre,
25 so on. It will be appreciated by a person skilled in the art that the above-mentioned

environment may refer an indoor environment within the zone conditioned or regulated by the air-conditioning system. It will also be appreciated by a person skilled in the art that the method and the system for scheduling the HVAC system, for optimizing a plurality of building performance parameters in providing an environment with respect to a zone of the building, may also be applied or employed with respect to each zone (e.g., each predetermined or selected zone) of the building. Accordingly, the building performance parameters with respect to each zone of the building may be optimized.

[0022] Various aspects of what is described herein seek to provide a method for scheduling a heating, ventilation and air-conditioning (HVAC) system. The HVAC system may include an air conditioning plant, at least one air handling unit (AHU) in (fluid) connection with the air conditioning plant, and the at least one AHU is configured to serve a plurality of zones. The proposed method may include obtaining zone environmental information (e.g. zone-level information of each zone at a present time period) including a zone temperature, a zone air quality indicator (e.g. zone carbon dioxide (CO₂) concentration data) and zone set-points (e.g. zone temperature set-points and zone air quality set-points) for each of the plurality of zones. The proposed method may also include obtaining AHU-level information at the present time period including conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air. The proposed method may further include determining, for the at least one AHU (at the AHU-level) and for the present time period of a prediction horizon, a minimum conditioned air supply rate (e.g. at zone-level) and a return air ratio based on a conditioned air function of parameters (e.g. the obtained zone-level information of each zone and the obtained AHU-level information including the zone temperature, the conditioned air temperature, the fresh

air temperature, the zone air quality indicator and the conditioned air quality indicator) so as to meet all the zone set-points for the plurality of zones.

[0023] According to some embodiments, the zone air quality indicator may include zone CO₂ concentration data. The CO₂ concentration data at a succeeding time period within the prediction horizon may be determined by a CO₂ concentration dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, CO₂ generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

[0024] The proposed method may include three stages. The first stage of the proposed method may include minimizing an energy cost function for each AHU (e.g. determining a minimum conditioned air supply rate and a return air ratio for the AHU based on the obtained zone-level information of each zone and the AHU-level information). That may mean that at the first stage, the proposed method includes determining a minimum conditioned air supply rate and a return air ratio for each AHU that the air conditioning plant is in connection with.

[0025] The second stage of the proposed method may include minimizing an energy consumption of the air conditioning plant (e.g. a chiller plant) at the air conditioning plant-level (e.g. the product of an efficiency of the air conditioning plant and the air conditioning load) based on an efficiency of the air conditioning plant (e.g. varying with the air conditioning load) and a summation of air conditioning load of all the AHUs (e.g. an air conditioning load of each AHU including a summed air conditioning load of each zone served by the AHU subject to the return air ratio). That may mean that at the second stage, the proposed method includes determining an optimal air conditioning load and consequently a damper opening (e.g. AHU level damper) configured to vary the return air ratio by adjusting positions of the damper opening (e.g. the opening of a AHU level damper).

At the second stage, the determined minimum conditioned air supply rate may be maintained (e.g. fixed) and the air quality requirements (the zone set-points) may be met while the determined return air ratio may be optimized. By optimizing the return air ratio, the air conditioning load may be corresponding optimized which in turn affects the efficiency of the air conditioning plant. Each AHU may have a damper (e.g. AHU level damper) for fresh air supply, and the damper (e.g. AHU level damper) may ensure air quality in each zone by mixing fresh air and return air in the AHU before being pumped into each individual zone.

[0026] The third stage of the proposed method may include optimizing the energy consumption (e.g. a fan energy consumption) for each AHU. That may mean that at the third stage, the proposed method includes mapping an AHU fan supply pressure and a zone damper opening to the conditioned air supply rates. Each zone may have its own zone damper for conditioned air supply. The zone-dampers may deal with zone temperature. Accordingly, the minimum conditioned air supply rate determined at the first stage may be optimized at the third stage, that is, the optimized air supply rate may not be the minimum. That may mean the optimized air supply rate at the third stage may be greater than the minimum conditioned air supply rate determined at the first stage, for example, due to the adjusted return air ratio at the second stage.

[0027] In some instances, aspects of the systems and techniques described here provide technical improvements and advantages over existing approaches. For example, the proposed systems and methods may provide a technical solution for scheduling a HVAC system, meeting zone-wise thermal comfort and air quality requirements (e.g. set-points), while ensuring low energy consumption. The proposed method may be computationally viable and scalable for real-time operations. For example, the proposed method may be implemented for scheduling a HVAC having multiple AHUs each of AHUs serving multiple zones meeting all zone-wise thermal comfort and air quality requirements (e.g. set-points).

For example, the proposed method may be implemented for scheduling a HVAC having multiple AHUs each of AHUs serving multiple zones but meeting all zone thermal comfort but selected zone air quality requirements (e.g. that are served by one AHU or selected AHUs).

5 [0028] The following examples pertain to various aspects of the present disclosure.

[0029] Example 1 is a method for scheduling a heating, ventilation and air-conditioning (HVAC) system, wherein the HVAC system includes an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, and the at least one AHU is configured to serve a plurality of zones. The method including: obtaining zone
10 environmental information including a zone temperature, a zone air quality indicator and zone set-points for the plurality of zones, the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points; obtaining conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to
15 mix with return air of the conditioned air to form pre-conditioned air; and determining, for the at least one AHU and for a prediction horizon, a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-
20 points for the plurality of zones.

[0030] In Example 2, the subject matter of Example 1 may optionally include that the conditioned air quality indicator is determined by an air quality indicator of the return air, an air quality indicator of the fresh air and the return air ratio.

[0031] In Example 3, the subject matter of Example 1 or Example 2 may optionally include
25 that the zone air quality indicator includes zone carbon dioxide (CO₂) concentration data,

wherein the zone carbon dioxide (CO₂) concentration data at a succeeding time period within the prediction horizon is determined by a carbon dioxide (CO₂) concentration dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, carbon dioxide (CO₂) generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

[0032] In Example 4, the subject matter of any one of Examples 1 to 3 may optionally include that the zone temperature of a succeeding time period is defined as a temperature linear function of the zone temperature of a present time period within the prediction horizon, a zone air conditioning load, a mass flow rate of conditioned air supply in a respective zone of the plurality of zones and the conditioned air temperature.

[0033] In Example 5, the subject matter of any one of Examples 1 to 4 may optionally include that the at least one AHU comprises a damper opening configured to vary the return air ratio by adjusting positions of the damper opening.

[0034] In Example 6, the subject matter of Example 5 may optionally include determining an average return air ratio across the positions of the damper opening, and determining differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.

[0035] In Example 7, the subject matter of Example 6 may optionally include setting a lower bound and an upper bound for an air conditioning load associated with the at least one AHU, wherein the lower bound is set when the return air ratio is at a maximum and the upper bound is set when the return air ratio is zero, wherein the air conditioning load is set between the lower bound and the upper bound.

[0036] In Example 8, the subject matter of Example 7 may optionally include (i) obtaining a parameter relating to a coefficient of performance of the air conditioning plant; (ii)

determining the parameter relating to the coefficient of performance of the air conditioning plant to be a first parameter if the air conditioning load associated with the at least one AHU is less than or equal to a first predetermined threshold; (iii) determining the parameter relating to the coefficient of performance of the air conditioning plant to be a second
5 parameter if the air conditioning load associated with the at least one AHU is less than or equal to a second predetermined threshold and greater than or equal to the first predetermined threshold; and (iv) continuing step as described in (iii) until the air conditioning load associated with the at least one AHU is greater than a last predetermined threshold, and determining the parameter relating to the coefficient of performance of the
10 air conditioning plant to be a last parameter.

[0037] In Example 9, the subject matter of Example 8 may optionally include optimizing the return air ratio based on an optimization function of the determined parameter relating to the coefficient of performance of the air conditioning plant and the differences between the return air ratio when the damper opening is at each of the positions and the average
15 return air ratio.

[0038] In Example 10, the subject matter of Example 9 may optionally include mapping a conditioned air coupling based on a zone damper opening for the plurality of zones and a fan supply air pressure for the at least one AHU to a mass flow rate of conditioned air supply for the plurality of zones.

20 [0039] In Example 11, the subject matter of Example 10 may optionally include communicating the optimized return air ratio to a scheduler; receiving, at the scheduler, the optimized return air ratio and energy efficiency data of the air conditioning plant; balancing the optimized return air ratio against the parameter relating to the coefficient of performance of the air conditioning plant for a subsequent time period; calculating an air supply strategy
25 based on the balancing, the air supply strategy comprising a conditioned air supply

allocation for the plurality of zones in the subsequent time period to minimise energy consumption of the air conditioning plant while aiming to meet the zone set-points; and delivering the air supply strategy to the plurality of zones.

[0040] Example 12 is system for scheduling a heating, ventilation and air-conditioning (HVAC) system. The HVAC system may include an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, the at least one AHU is configured to serve a plurality of zones. The system may include: a zone module configured to obtain zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for the plurality of zones, the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points; an input module configured to obtain conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air; and a scheduler, for the at least one AHU and for a prediction horizon, configured to determine a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-points for the plurality of zones.

[0041] In Example 13, the subject matter of Example 12 may optionally include that the conditioned air quality indicator is determined by an air quality indicator of the return air, an air quality indicator of the fresh air and the return air ratio.

[0042] In Example 14, the subject matter of Example 12 or Example 13 may optionally include that the zone air quality indicator includes zone carbon dioxide (CO₂) concentration data, wherein the zone carbon dioxide (CO₂) concentration data at a succeeding time period within the prediction horizon is determined by a carbon dioxide (CO₂) concentration

dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, carbon dioxide (CO₂) generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

5 [0043] In Example 15, the subject matter of any one of Examples 12 to 14 may optionally include that the zone temperature of a succeeding time period is defined as a temperature linear function of the zone temperature of a present time period within the prediction horizon, a zone air conditioning load, a mass flow rate of conditioned air supply in a respective zone of the plurality of zones and the conditioned air temperature.

10 [0044] In Example 16, the subject matter of any one of Examples 12 to 15 may optionally include that the at least one AHU comprises a damper opening configured to vary the return air ratio by adjusting positions of the damper opening.

[0045] In Example 17, the subject matter of Example 16 may optionally include that the scheduler is further configured to: determine an average return air ratio across the positions
15 of the damper opening and determining differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.

[0046] In Example 18, the subject matter of Example 17 may optionally include that the scheduler is further configured to: set a lower bound and an upper bound for an air conditioning load associated with the at least one AHU, wherein the lower bound is set when
20 the return air ratio is at a maximum and the upper bound is set when the return air ratio is zero, wherein the air conditioning load is set between the lower bound and the upper bound.

[0047] In Example 19, the subject matter of Example 18 may optionally include that the input module is further configured to: (i) obtain a parameter relating to a coefficient of performance of the air conditioning plant; wherein the scheduler is further configured to:
25 (ii) determine the parameter relating to the coefficient of performance of the air conditioning

plant to be a first parameter if the air conditioning load associated with the at least one AHU is less than or equal to a first predetermined threshold; (iii) determine the parameter relating to the coefficient of performance of the air conditioning plant to be a second parameter if the air conditioning load associated with the at least one AHU is less than or equal to a second predetermined threshold and greater than or equal to the first predetermined threshold; and (iv) continue step as described in (iii) until the air conditioning load associated with the at least one AHU is greater than a last predetermined threshold, and determine the parameter relating to the coefficient of performance of the air conditioning plant to be a last parameter.

10 **[0048]** In Example 20, the subject matter of Example 19 may optionally include that the scheduler is further configured to: optimize the return air ratio based on an optimization function of the determined parameter relating to the coefficient of performance of the air conditioning plant and the differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.

15 **[0049]** FIG. 1 is a flow chart showing an example method 100 for scheduling a heating, ventilation and air-conditioning (HVAC) system, according to various embodiments of the present disclosure. The HVAC system may include an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, and the at least one AHU is configured to serve a plurality of zones.

20 **[0050]** In the context of various embodiments, the term “heating, ventilation, and air conditioning (HVAC)” refers to the use of various technologies to control the temperature, humidity, and/or purity of the air in an enclosed space so as to provide thermal comfort and desirable indoor air quality. It should be appreciated that the proposed method is intended to be used in any air conditioning system including any combination of heating, cooling, refrigeration, ventilation, and any other air conditioning.

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[0051] According to various non-limiting embodiments, the method 100 may include the following steps.

[0052] At step 101, zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for each of the plurality of zones may be obtained.

5 The zone set-points for each of the plurality of zones may include zone temperature set-points and zone air quality set-points. The set-points may include a lower bound value and an upper bound value. The at least one AHU may serve a plurality of zones and, accordingly, the step 101 may include obtaining zone environmental information from each of the plurality of zones simultaneously or consecutively. Each of the plurality of zones may have
10 a temperature sensor and a zone air quality indicator sensor which provide zone environmental information of the respective zone. The zone set-points may be set by a user of the respective zone of the plurality of zones or centrally set (defined as desirable ranges of zone temperature and zone air quality indicator). The zone set-points may be set differently for different zones of the plurality of zones.

15 [0053] At step 103, conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air may be obtained. The conditioned air may be provided by the air conditioning plant in connection with the at least one AHU to the at least one AHU. A temperature sensor and a zone air
20 quality indicator sensor may also be arranged to measure conditioned air temperature and conditioned air quality indicator of the conditioned air that is provided to the at least one AHU. Similarly, a temperature sensor and a zone air quality indicator sensor may also be arranged to measure fresh air temperature of fresh air. The return air refers to the air that returns to the HVAC system from the plurality of zones that the at least one AHU

serves. That is, the return air refers to a combined return air that combines respective zone return air of the plurality of zones that the at least one AHU serves.

[0054] It should be appreciated that although a temperature sensor and a zone air quality indicator sensor are described herein the two sensors may be combined as one sensor, and
5 other sensor may be used as long as the sensor provides the information required.

[0055] At step 105, for the at least one AHU and for a prediction horizon, a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator may be
10 determined so as to collectively meet the zone set-points for the plurality of zones. In some embodiments, the minimum conditioned air supply rate and the return air ratio may be determined to meet each and every zone set-points of the plurality of zones that the at least one AHU serves. In some embodiments, the minimum conditioned air supply rate and the return air ratio may be determined to meet the zone set-points of selected zones of the
15 plurality of zones that the at least one AHU serves. The return air ratio refers to a ratio of a quantity (e.g. volume) of the return air to a quantity (e.g. volume) of the conditioned air.

[0056] FIG. 2 is a block diagram showing an example system 200 for scheduling a HVAC system, according to various embodiments of the present disclosure. The HVAC system may include an air conditioning plant, at least one air handling unit (AHU) in connection
20 with the air conditioning plant, the at least one AHU is configured to serve a plurality of zones.

[0057] According to various non-limiting embodiments, the system 200 may include a zone module 210, an input module 220 and a scheduler 230. The system 200 may further include other modules that are not shown in FIG. 2. The system 200 may be integral to the HVAC
25 system or a separate system attached to the HVAC system.

[0058] According to various non-limiting embodiments, the zone module 210 may be configured to obtain zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for each of the plurality of zones. The zone set-points for each of the plurality of zones may include zone temperature set-points and zone air quality set-points. The zone module 210 may include a plurality of sub-modules each of which is disposed at a respective zone of the plurality of zones. The zone module 210 may further include a master sub-module in communication with each of the plurality of sub-modules and processing respective zone environmental information from the plurality of zones. The processed zone environmental information may be provided to the scheduler 230.

[0059] According to various non-limiting embodiments, the input module 220 may be configured to obtain conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air. The input module 220 may be further configured to obtain air quality indicator of the fresh air. The input module 220 may include a first sub-module configured to obtain conditioned air temperature and conditioned air quality indicator of the conditioned air associated with the at least one AHU and a second sub-module configured to obtain fresh air temperature and air quality indicator of the fresh air. The input module 220 may provide the obtained information to the scheduler 230.

[0060] According to various non-limiting embodiments, the scheduler 230 may, for the at least one AHU and for a prediction horizon, be configured to determine a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to

collectively meet the zone set-points for each of the plurality of zones. The prediction horizon may include multiple discrete time intervals. The at least one AHU may include multiple AHUs and, accordingly, the scheduler 230 may, for a respective AHU of the multiple AHUs and for a prediction horizon, be configured to determine a minimum
5 conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including a zone temperature, a conditioned air temperature, a fresh air temperature, a zone air quality indicator and a conditioned air quality indicator obtained from a plurality of zones that the respective AHU serves, so as to collectively meet the zone set-points for the plurality of zones that the respective AHU serves. The scheduler 230 may
10 be configured to output a schedule of optimized data or information (e.g. conditioned air supply rate, return air ratio, conditioning load) for each zone and/or AHU and/or conditioning plant of the building (e.g., over a prediction horizon) to provide optimized energy consumption and occupant thermal comfort, such as by solving the optimization or scheduling problem described herein.

15 **[0061]** According to various non-limiting embodiments, the system 200 may further include a controller such as, but not limited to, a VAV controller, a chiller controller and a fan controller, operating based on output from the scheduler 230, typically managed by a Building Energy Management System (BEMS).

[0062] FIG. 3 is a block diagram showing an example HVAC system 300, according to
20 various embodiments of the present disclosure. The HVAC system 300 may include an air conditioning plant 320, an air handling unit (AHU) 310 in (fluid) connection with the air conditioning plant 320, and the AHU 310 is configured to serve a plurality of zones (e.g. zone 1, ..., zone i , ..., zone n), for example, zones 311, 312, and 313 as shown in FIG. 3. The method 100 as described above may be implemented for scheduling the HVAC system
25 300. The HVAC system 300 may be scheduled (e.g. controlled) by the system 200. The air

conditioning plant 320 may provide (e.g. produce) conditioned air 301 for supplying to the AHU 310. The AHU 310 may provide (e.g. circulate) the conditioned air 301 to the plurality of zones, for example, 311, 312 and 313. Returned air 302 from the plurality of zones 311, 312 and 313 may mix with fresh air 303 to form pre-conditioned air 304 and the pre-
5 conditioned air 304 of the returned air 302 and the fresh air 303 may be circulated to the air conditioning plant 320. The pre-conditioned air 304 may be conditioned by conditioned water 306 (e.g. chilled water, hot water) to produce conditioned air 301.

[0063] According to various non-limiting embodiments, the zone module 210 (not shown in FIG. 3) of the system 200 may be arranged in the plurality of zones 311, 312 and 313.
10 The zone module 210 may be configured to obtain zone environmental information of the plurality of zones 311, 312 and 313. For example, zone 311 is a meeting room, zone 312 is an office room shared by several staffs and zone 313 is an office room occupied by one staff and office equipment(s).

[0064] In some embodiments, the zone module 210 may be configured to obtain zone
15 environmental information of the plurality of zones 311, 312 and 313, that is, to obtain zone environmental information of all the zones that the AHU 310 serves. In some embodiments, the zone module 210 may be configured to obtain zone environmental information of the zones 312 and 313, that is, to obtain zone environmental information of selected zones that the AHU 310 serves. That may mean that for the AHU 310 that serves the plurality of zones
20 311, 312 and 313 and for the prediction horizon, the minimum conditioned air supply rate and the return air ratio may be determined based on the zone environmental information of the selected zone(s). That may also mean that for the AHU 310 that serves the plurality of zones 311, 312 and 313 and for the prediction horizon, the minimum conditioned air supply rate and the return air ratio may be determined based on the dynamic zone environmental

information of the selected zone(s) and a pre-set zone environmental information of the remaining zone(s) of the plurality of zones.

[0065] In some embodiments, the zone module 210 may be configured to obtain zone environmental information including a zone temperature, a zone air quality indicator, zone temperature set-points and zone air quality set-points for each of the plurality of zones 311, 312 and 313, that is, to obtain all the zone environmental information of all the zones that the AHU 310 serves. In some embodiments, the zone module 210 may be configured to obtain zone environmental information including a zone temperature and zone temperature set-points for each of the plurality of zones 311, 312 and 313, and to obtain zone environmental information including a zone air quality indicator and zone air quality set-points for zones 312 and 313, that is, to obtain part of the zone environmental information of the selected zones that the AHU 310 serves. That may mean that for the AHU 310 that serves the plurality of zones 311, 312 and 313 and for the prediction horizon, the minimum conditioned air supply rate and the return air ratio may be determined based on the zone environmental information of the selected zone(s) and part of the zone environmental information of the remaining zone(s) of the plurality of zones. That may also mean that for the AHU 310 that serves the plurality of zones 311, 312 and 313 and for the prediction horizon, the minimum conditioned air supply rate and the return air ratio may be determined based on the zone environmental information of the selected zone(s), part of the zone environmental information of the remaining zone(s) and a pre-set other part of the zone environmental information of the remaining zone(s) of the plurality of zones.

[0066] According to various non-limiting embodiments, the input module 220 (not shown in FIG. 3) of the system 200 may be configured to obtain conditioned air temperature and conditioned air quality indicator of conditioned air associated with the AHU 310. The input module 220 may be further configured to obtain fresh air temperature of fresh air configured

to mix with return air of the conditioned air to form pre-conditioned air. In some embodiments, the input module 220 may include a temperature sensor 314 configured to obtain conditioned air temperature. In some embodiments, the input module 220 may further include a pressure sensor 315 configured to obtain conditioned air pressure. In some
 5 embodiments, the input module 220 may further include an air quality sensor (not shown) configured to obtain air quality indicator of conditioned air. In some embodiments, the input module 220 may further include a temperature sensor 316 and an air quality sensor 317 (e.g. CO₂ concentration sensor) configured to obtain temperature and air quality indicator of return air.

10 **[0067]** According to various non-limiting embodiments, the scheduler 230 (not shown in FIG. 3) of the system 200 may be configured to determine, for the AHU 310 and for a prediction horizon, a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air
 15 quality indicator so as to meet the zone set-points for the plurality of zones 311, 312 and 313.

[0068] According to various non-limiting embodiments, the zone air quality indicator may include zone carbon dioxide (CO₂) concentration data, particulate matter 2.5 (PM_{2.5}) data, humidity data, aeroallergen data (e.g. dust mites), chemical hazard data, air quality index
 20 and the like.

[0069] A prediction model for providing conditioned air with thermal and air quality constraints will be described in the following.

[0070] According to various non-limiting embodiments, a model for energy cost function J for providing conditioned air is provided, as shown be below:

25 **[0071]** $\min J = \sum_{k=1}^N (\sum_u P_{u,f}(\dot{m}_1(k), \dots, \dot{m}_z(k)) + P_c(\dot{m}_1(k), \dots, \dot{m}_z(k))) \Delta$

$$\text{subject to: } (\forall r \in \{1, \dots, z\})(\forall k) T_r(k+1) = f_r(T_r(k), \dot{m}_r(k), T_c(k), Q_r(k)) \quad (1)$$

$$(\forall r \in \{1, \dots, z\})(\forall k) T_{r,l}(k) \leq T_r(k) \leq T_{r,u}(k) \quad (2)$$

$$(\forall k)(\forall u) h(\dot{m}_{u_1}(k), \dots, \dot{m}_{u_z}(k), A_{u_1}(k), \dots, A_{u_z}(k), p_u) = 0 \quad (3)$$

[0072] where

- $P_{u,l}(k)$ – the fan power function of AHU u during the discrete time interval k ,
- $P_c(k)$ – the air conditioning plant power function during the discrete time
- 5 interval k ,
- Δ – the sampling period, i.e., the length of the chosen discrete-time interval,
- z – the number of zones in a target building,
- u – one AHU,
- $\{u_1, \dots, u_z\}$ – individual zones in AHU u ,
- 10 • f_r – the thermal dynamic model of zone r ,
- $T_r(k)$ – temperature of zone r during the discrete time interval k ,
- $\dot{m}_r(k)$ – mass flow rate of conditioned air supply in zone r during k ,
- $T_c(k)$ – temperature of cool air supply during the discrete time interval k ,
- $Q_r(k)$ – ambient air conditioning load of zone r during the discrete time
- 15 interval k ,
- $[T_{r,l}(k), T_{r,u}(k)]$ – thermal set-points of zone r , i.e., lower/upper bounds of temperature,
- h – coupling of zone flow rates, zone damper openings, AHU supply pressure,
- 20 • A_{u_r} – VAV zone damper opening of zone u_r in AHU u during k ,
- p_u – fan supply air pressure in AHU u .

[0073] The cost function J may be defined only based on the air-side information, where the AHU fan power function and air conditioning plant power function are both defined

over zone conditioned air mass flow rates (e.g. conditioned air supply rates), which may be learned via data. The above constraint (1) is about zone thermal dynamics, where a bilinear model is adopted:

$$\begin{aligned}
 T_r(k+1) &= f_r(T_r(k), \dot{m}_r(k), T_c(k), Q_r(k)) \\
 &= a_r(k)T_r(k) - b_r(k)\dot{m}_r(k)(T_r(k) - T_c(k)) + Q_r(k).
 \end{aligned}$$

[0074] By introducing a new variable $\dot{g}_r(k) := \dot{m}_r(k)(T_r(k) - T_c(k))$, we have

$$T_r(k+1) = a_r(k)T_r(k) - b_r(k)\dot{g}_r(k) + Q_r(k),$$

which becomes a linear model and may be identified effectively. The ambient air conditioning load $Q_r(k)$ is considered piecewise constant, as the change of ambient conditions is a slow process compared with zone thermal dynamics. The zone temperature of a succeeding time period may be defined as a temperature linear function of the zone temperature of a present time period within the prediction horizon, a zone air conditioning load, a mass flow rate of the conditioned air supply in a respective zone of the plurality of zones and the conditioned air temperature.

[0075] The above constraint (2) is about the occupant's thermal comfort set-points, for example, a pre-determined range, e.g., 23°C – 26°C during working hours, and 28°C – 30°C during night hours. An occupant may online input his/her thermal preference, or use a machine-learning method to learn a specific occupant's thermal preference, based on time, ambient setting, and the occupant's body movements. Zone CO₂ measurements, zone occupancy may be determined via a machine learning prediction model. If the zone is not occupied, its thermal set-points may be simply set as, e.g., 28°C – 30°C; otherwise, 23°C – 26°C.

[0076] The above constraint (3) is about coupling of zone cool air supplies due to the shared AHU fan and air duct network. The coupling function h may be defined based on standard

fluid dynamic models that rely on prior knowledge about the layout information of the air duct network.

[0077] According to various non-limiting embodiments, the zone air quality indicator may include zone carbon dioxide (CO₂) concentration data. The zone carbon dioxide (CO₂) concentration data at a succeeding time period within the prediction horizon may be determined by a carbon dioxide (CO₂) concentration dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, carbon dioxide (CO₂) generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

[0078] In zone i (or r relating to constraints (1) to (3)) of the plurality of zones (e.g. zone 1, ..., zone i (or r relating to constraints (1) to (3)), ..., zone n), a prediction model for the zone air quality indicator (e.g. CO₂ concentration), $W_i(k+1)$, at a discrete time interval $(k+1)$ is described as follows. The air quality indicator (e.g. fresh air CO₂ concentration) at each time interval k , $W_o(k)$ ppm, is assumed known.

$$[0079] W_i(k+1)V_i = W_i(k)V_i + \frac{1}{\rho}\dot{m}_i(k)\Delta(W_s(k) - W_i(k)) + B_i(k)\Delta \quad (4)$$

where

- $W_i(k)$ – CO₂ concentration in zone i during the discrete time interval k ,
- $W_s(k)$ – CO₂ concentration in conditioned air during the discrete time interval k ,
- $B_i(k)$ – CO₂ generation rate of occupants and equipment in zone i during the discrete time interval k ,
- V_i – the air volume of zone i ,
- ρ – air density, and
- $\dot{m}_i(k)$ – mass flow rate of conditioned air in zone i during the discrete time interval k .

[0080] Let $d_r(k) \in [0,1]$ be the percentage of returned air recycled (e.g. a return air ratio) for air conditioning during the discrete time interval k . Assuming no air loss in the duct network (otherwise, compensation terms are needed), CO₂ concentration in the conditioned air at the exit of the air conditioning plant (e.g. an exit coil) is determined by CO₂ concentrations of returned air and the fresh air, respectively:

$$[0081] \quad W_s(k) \sum_i \dot{m}_i(k) = d_r(k) \sum_i \dot{m}_i(k) W_i(k) + \sum_i (\dot{m}_i(k) - d_r(k) \dot{m}_i(k)) W_o(k) \quad (5)$$

[0082] According to various non-limiting embodiments, the conditioned air quality indicator, $W_s(k)$, is determined by an air quality indicator of the return air, $W_i(k)$, an air quality indicator of the fresh air, $W_o(k)$, and the return air ratio $d_r(k)$.

[0083] Assume that the CO₂ concentration set-points $[W_{i,L}, W_{i,H}]$ in an occupied zone i at the discrete time interval k are given as follows:

$$[0084] \quad (\forall i, k) W_{i,L} \leq W_i(k) \leq W_{i,H} \quad (6)$$

where $[W_{i,L}, W_{i,H}]$ denotes the minimum and maximum required CO₂ concentrations, i.e., the air quality requirement in zone i . The above constraints (1) to (6) may allow a user to achieve high energy saving in HVAC control, while ensuring thermal and air quality constraints.

[0085] FIG. 4 is a block diagram showing an example method 400 for scheduling a HVAC system, according to various embodiments of the present disclosure. The HVAC system may include an air conditioning plant 401 and AHU 1 to AHU m . The method 400 may include the features of the method 100.

[0086] The method 400 may include three computational stages including a stage one 410, a stage two 420 and a stage three 430. The stage one 410 may include steps in zones 1... n of the plurality of zones that are served by AHU 1, ..., and zones 1... n of the plurality of zones that are served by AHU m . The stage two 420 may include steps across the AHU 1, ..., and AHU m and the air conditioning plant 401. The stage three 430 may include steps

in zones $1 \dots n$ of the plurality of zones that are served by AHU 1, ..., and zones $1 \dots n$ of the plurality of zones that are served by AHU m .

Stage one 410

[0087] At Stage one 410, a minimum conditioned air supply rate and a return air ratio for
5 each of the AHU 1 to AHU m will be determined simultaneously or consecutively.

[0088] According to various non-limiting embodiments, air conditioning loads in the plurality zones associated with the concerned AHU may be summed as the cost function, and the following constraints may be considered in zone i :

- (a) the thermal dynamics of each zone i (e.g. zone temperature),
 - 10 (b) the thermal comfort range of each zone i (e.g. zone temperature set-points),
 - (c) the CO₂ concentration dynamics of each zone i (e.g. zone air quality indicator),
- and

(d) the allowed CO₂ concentration range for each zone i (e.g. zone air quality set-points).

[0089] It is assumed that the initial zone temperature $T_i(0)$, initial zone CO₂ concentration
15 $W_i(0)$, the zone-wise ambient air conditioning load generating function $v_i(k)$, the zone-wise CO₂ generation rate function $B_i(k)$ and the fresh air CO₂ concentration function $W_o(k)$ are all known. The zone-wise conditioned air supply rate $\dot{m}_i(k)$ and the AHU return air ratio $d_r(k)$ may be determined at stage one 410 by the following algorithm (7).

$$\begin{aligned}
 & \min_{\dot{m}_i(k), d_r(k)} \sum_{k=0}^{H_p} c_p \eta(k) \left((1 - d_r(k))(T_{oa} - T_c) \sum_i \dot{m}_i(k) + d_r(k) \sum_i \dot{m}_i(k)(T_i(k) - T_c) \right) \\
 & \text{s.t. } \forall i, k, T_i(k+1) + \alpha_1 T_i(k) + \alpha_2 \dot{m}_i(k)(T_i(k) - T_c) = v_i(k) \\
 & \quad T_{il} \leq T_i(k) \leq T_{ih} \\
 & \quad W_i(k+1)V_i = W_i(k)V_i + \rho^{-1} \dot{m}_i(k)(W_s(k) - W_i(k)) + B_i(k) \\
 & \quad W_s(k) \sum_i \dot{m}_i(k) = d_r(k) \sum_i \dot{m}_i(k)W_i(k) + (1 - d_r(k)) \sum_i \dot{m}_i(k)W_o(k) \quad (7)
 \end{aligned}$$

where

- c_p – specific heat capacity of air,
- $\eta(k)$ – the efficiency of the air conditioned plant during the discrete time interval k ,
- T_{oa} – Temperature of fresh air,
- T_c – Temperature of conditioned air,
- 5 • $T_i(k)$ – Temperature of zone i during the discrete time interval k ,
- α_1 and α_2 – constants for each prediction horizon (e.g. adjustable for different predication horizons).

[0090] Assume that the temperature set-points $[T_{i,l}, T_{i,h}]$ in an occupied zone i at the discrete time interval k are given as above constraint (4), where $[T_{i,l}, T_{i,h}]$ denotes the minimum and
 10 maximum required zone temperature in zone i .

[0091] The above algorithm (7) includes the constraints (2), (4), (5) and (6). For example, a user may replace the constraints (4) to (6) (e.g. the CO₂ concentration dynamic model for each zone) with another dynamic model, and the same three-stage architecture may still work, as long as the output is the zone-wise conditioned air supply rates that ensures both
 15 thermal comfort and CO₂ concentration in each zone.

[0092] In the Table 1 shown below, for an AHU containing 100 zones and for a sampling period of 15 minutes, it takes only 4.98 seconds to complete the computation for an 8-step prediction horizon. The computation time may increase to 26.37 seconds for a 32-step prediction horizon, which is more than enough for practical applications.

20 [0093] Table 1 Computation time for an 8-step and a 32-step prediction horizon

Number of zones	Computation time (2 hrs)	Computation time (8 hrs)
10	0.58 s	2.62 s
20	1.03 s	4.55 s
50	3.38 s	12.56 s
100	4.98 s	26.37 s
150	7.51 s	32.96 s
200	10.33 s	51.20 s

[0094] The first column of Table 1 shows the number of zones that the AHU serves. The second column of Table 1 shows the computation time for an 8-step prediction horizon. The third column of Table 1 shows the computation time for a 32-step prediction horizon. Each step represents a 15-minute sampling period and thus an 8-step prediction horizon represents
5 a 2-hour time period. Similarly, a 32-step prediction horizon represents an 8-hour time period.

Stage two 420

[0095] According to various non-limiting embodiments, at Stage two 420, the zone-wise air supply rate determined from Stage one 410 may be fixed and the return air ratio in the AHU
10 may be adjusted. This may essentially adjust an air conditioning load of the AHU by increasing or reducing fresh air supply, and consequently adjust the building air-side air conditioning load sensed at the air conditioned plant side, which eventually affects the air conditioned plant efficiency. More explicitly, assume that the air conditioned plant efficiency COP (Coefficient of Performance) is known and represented by $\eta(k)$, which may
15 be represented as a function of the air-side air conditioning load as described hereafter.

[0096] According to various non-limiting embodiments, two metrics may be minimized: the first one is the overall air conditioning plant energy consumption captured by the product of the COP and the air-side air conditioning load; the second one is the difference between any two AHUs' fresh air supply rates – that is, the supply fresh air CO₂ concentrations in
20 individual AHUs should be similar to each other. The first metric is critical for an energy saving purpose. The second one is from a tenant's viewpoint, which, however, is not critical for energy saving. A user may add any other optimization metric, as long as it can be represented as a function of the AHU air conditioning load.

[0097] According to various non-limiting embodiments, at stage two 420, the method 400
25 may include (i) obtaining a parameter relating to a coefficient of performance of the air

- conditioning plant; (ii) determining the parameter relating to the coefficient of performance of the air conditioning plant to be a first parameter if the air conditioning load associated with the at least one AHU is less than or equal to a first predetermined threshold; (iii) determining the parameter relating to the coefficient of performance of the air conditioning
- 5 plant to be a second parameter if the air conditioning load associated with the at least one AHU is less than or equal to a second predetermined threshold and greater than or equal to the first predetermined threshold; and (iv) continuing step as described in (iii) until the air conditioning load associated with the at least one AHU is greater than a last predetermined threshold, and determining the parameter relating to the coefficient of performance of the
- 10 air conditioning plant to be a last parameter. That may mean the parameter relating to a coefficient of performance of the air conditioning plant (e.g. $\eta(k)$ the efficiency of the air conditioned plant during the discrete time interval k) varies according to the air conditioning load associated with the AHU 1 to AHU m . When the air conditioning load is too high or too low, the efficiency of the air conditioned plant may become lower.
- 15 **[0098]** According to various non-limiting embodiments, the method 400 may further include optimizing the return air ratio based on an optimization function of the determined parameter relating to the coefficient of performance of the air conditioning plant and the differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.
- 20 **[0099]** According to various non-limiting embodiments, the AHU 1 to AHU m (including AHU 1, ..., AHU j ..., AHU m) may each include a damper opening configured to vary the return air ratio by adjusting positions of the damper opening. An average return air ratio, $\bar{d}_r(k)$ across the positions of the damper opening may be determined, and differences between the return air ratio when the damper opening is at each of the positions and the

average return air ratio, $\sum_{j=1}^{n_a} (d_r^j(k) - \bar{d}_r(k))^2$, n_a representing the number of AHU (e.g. m) may be consequently determined.

[00100] Accordingly to various non-limiting embodiments, the AHU damper opening, i.e., the return air ratio in the AHU, may be adjusted e.g., from 0% to 100% opening, and the minimum conditioned air supply rate determined in Stage one 410 may be maintained to ensure satisfaction of the air quality requirement in each AHU. Let $\bar{Q}_j(k)$ and $\underline{Q}_j(k)$ denote the maximum and minimum allowed air conditioning loads associated with AHU j , $j \in (1, \dots, m)$, where $\bar{Q}_j(k)$ is determined by setting the return air ratio as 0, when supplying the same conditioned air supply rate calculated in Stage one 410; and $\underline{Q}_j(k)$ is determined based on the return air ratio and the cool air supply rate from Stage one 410. Then the actual chosen air conditioning load $Q_j(k)$ may not go beyond the upper and lower bounds. In various embodiments, the minimum conditioned air supply rate determined in Stage one 410 may include a range of minimum conditioned air supply rates and maintaining the minimum conditioned air supply rate may include maintaining the minimum conditioned air supply rate in the range. The minimum conditioned air supply rate determined in Stage one 410 may be optimized while being maintained in the range. The method 400 may include setting a lower bound (e.g., $\underline{Q}_j(k)$) and an upper bound (e.g., $\bar{Q}_j(k)$) for an air conditioning load associated with the at least one AHU. The air conditioning load may be set to be between the lower bound (e.g., $\underline{Q}_j(k)$) and upper bound (e.g., $\bar{Q}_j(k)$) so that the minimum conditioned air supply rate is in the range. The lower bound may be set when the return air ratio is at a maximum and the upper bound may be set when the return air ratio is zero. The air conditioning load may be set between the lower bound and the upper bound.

[00101] Accordingly to various non-limiting embodiments, the amount of fresh air may be optimized by virtue of varying the damper opening (e.g. varying the air conditioning

load). Accordingly, the return air ratio, being the ratio of a quantity (e.g. volume) of the return air to a quantity (e.g. volume) of the conditioned air (i.e., the mixed air of the fresh air and return air) may be optimized.

[00102] An algorithm (8) is presented for determining the air conditioning load. For example, some special AHUs may not be allowed to change their damper openings. In this case, the user may simply set the actual AHU air conditioning load to be the allowed lower bound, i.e., $Q_j(k) = \underline{Q}_j(k)$.

$$\begin{aligned}
 & \min_{d_r^j(k)} \sum_{k=0}^{H_p} \eta(k) \sum_{j=1}^{n_a} Q_j(k) + \sum_{j=1}^{n_a} (d_r^j(k) - \bar{d}_r(k))^2 \\
 \text{s.t.} \quad & \forall k, \quad \eta(k) = \begin{cases} \eta_1 & \text{if } \sum_{j=1}^{n_a} Q_j(k) \leq Q_{ch1} \\ \eta_2 & \text{if } Q_{ch1} \leq \sum_{j=1}^{n_a} Q_j(k) \leq Q_{ch2} \\ \vdots & \vdots \\ \eta_{m_a} & \text{if } \sum_{j=1}^{n_a} Q_j(k) > Q_{ch(m_a-1)} \end{cases} \\
 & \forall k, \forall j, \quad \underline{Q}_j(k) \leq Q_j(k) \leq \bar{Q}_j(k) \\
 & \forall k, \quad n_a \bar{d}_r(k) = \sum_{j=1}^{n_a} d_r^j(k) \\
 & Q_j(k) = (1 - d_r^j(k)) \sum_{i=1}^{n_z^j} \dot{m}_{ji}^*(k) (T_{oa} - T_c) + d_r^j(k) \sum_{i=1}^{n_z^j} \dot{q}_{ji}^*(k) \\
 & \underline{Q}_j(k) = (1 - d_r^{j*}(k)) \sum_{i=1}^{n_z^j} \dot{m}_{ji}^*(k) (T_{oa} - T_c) + d_r^{j*}(k) \sum_{i=1}^{n_z^j} \dot{q}_{ji}^*(k) \\
 & \bar{Q}_j(k) = \sum_{i=1}^{n_z^j} \dot{m}_{ji}^*(k) (T_{oa} - T_c)
 \end{aligned} \tag{8}$$

[00103] The above algorithm (8) may be effectively converted into a standard Mixed-Integer Linear Program (MILP), which may be solved efficiently, due to the relatively small number of AHUs. Table 2 shows below that for example, for a building with 100 AHUs and each AHU serving 100 zones (in row 5), it takes only 0.2 second to complete the Stage 2 computation, which optimizes the air conditioned plant efficiency.

[00104] Table 2 Computation time for a 32-step prediction horizon

Number of AHUs	Number of zones per AHU	Computation time (8 hrs)
10	100	0.13 s
20	100	0.15 s
50	100	0.18 s

100	100	0.2 s
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[00105] The first column of Table 2 shows the number of AHUs that the air conditioned plant is in connection with and thus provide conditioned air to. The second column of Table 2 shows the number of zones that each AHU serves. The third column of Table 2 shows the computation time for a 32-step prediction horizon.

Stage three 430

[00106] According to various non-limiting embodiments, to improve the air coupling function h described in constraint (3), a machine learning based method is developed that maps the AHU fan supply pressure and VAV zone damper openings to zone conditioned air supply rates. Essentially, instead of using the above constraint (3), the following constraint (3') is learnt:

$$[00107] \quad (\forall k) h(A_{u_1}(k), \dots, A_{u_z}(k), p_u) = (\dot{m}_{u_1}(k), \dots, \dot{m}_{u_z}(k)) \quad (3')$$

[00108] A simple multi-layer neural network as shown in FIG. 5 is used to learn the function h over a list of data obtained from a testbed. The outcome is shown with 90% prediction accuracy.

[00109] Due to the introduction of new constraint (3') to capture AHU zone-wise conditioned air coupling, the energy cost function J is updated, as follows in (9):

$$\min J_f = \sum_{k=0}^{H_P} \left(\sum_{i=1}^{n_z} a_i \dot{m}_i(k) \right)^b$$

$$\text{Subject to} \quad h(p_0(k), A_1(k), \dots, A_{n_z}(k)) = (\dot{m}_1(k), \dots, \dot{m}_{n_z}(k))$$

$$20 \quad (\forall k: 0 \leq k \leq H_P) p_0(k) \leq p_{cop}$$

$$\text{From Stage 2: } (\forall r: 0 \leq r \leq H_w) (\forall 1 \leq i \leq n_z) \sum_{k=0}^r \dot{m}_i(k) \geq Tok B_i(r)$$

$$\text{Output: } \{\dot{m}_i(k) | 1 \leq i \leq n_z, 0 \leq k \leq H_w\} \quad (9)$$

[00110] By introducing an efficient metaheuristic algorithm, this Stage three 430 as shown in the algorithm (9) may be solved in less than 2 minutes with an accuracy drop of 3.58% (see Table 3, row 5, column 6) with respect to the best solution that may be found. The experimental results are shown in Table 3 below, which includes an air coupling model
5 derived from machine learning.

[00111] Table 3 Computation time and inaccuracy for a prediction horizon of 4 hours

	zones = 100, prediction horizon = 4 hrs ($H_p = H_w = 16$)				
(Pop size, Iterations)	best	mean	std.	avg. time	avg. inaccuracy %
(30, 500)	145.6393	148.6822	2.6846	898.20 sec.	NA
(30, 100)	145.7937	150.2305	4.5486	186.89 sec.	1.04%
(30, 50)	149.5673	154.0123	3.3883	114.92 sec.	3.58%

** H_p - prediction horizon, i.e. 4 hours; H_w - prediction window of 15 minutes, i.e. 16 prediction windows $\times$ 15 minutes = 4 hours*

10 [00112] The method 400 may further include communicating the optimized return air ratio to a scheduler (e.g., the scheduler 230); receiving, at the scheduler, the optimized return air ratio and energy efficiency data of the air conditioning plant; balancing the optimized return air ratio against the parameter relating to the coefficient of performance of the air conditioning plant for a subsequent time period; calculating an air supply strategy based on
15 the balancing, the air supply strategy comprising a conditioned air supply allocation for the plurality of zones in the subsequent time period to minimise energy consumption of the air conditioning plant while aiming to meet the zone set-points; and delivering the air supply strategy to the plurality of zones.

[00113] The present HVAC scheduling method 400 described in this disclosure may
20 allow a distributive computation architecture, where Stage one 410 and Stage three 430 computation may be carried out over several servers, each of which takes care of only a few number of AHUs and relevant zones. Stage two may be carried out in one server. The

number of required servers for Stage one and Stage three computation may be determined by the number of AHUs. For example, currently, the proposed computational algorithm requires 2.5 minutes for each AHU based on a standard laptop. If a server can handle x AHUs simultaneously, while satisfying the maximum allowed computational time such as 2.5 minutes per AHU, then, to handle y AHUs simultaneously, we need y/x server. All servers handling individual AHUs may need to communicate with the server that is responsible for Stage two optimization.

[00114] Further experimental results will be described with reference to FIGS. 6 to 8.

[00115] FIG. 6 depicts a graph 610 showing a comparison of actual and estimated temperatures with the zone-wise ambience model with constraints (1) to (3), and a graph 620 showing errors between the actual and estimated temperatures, according to various embodiments of the present disclosure. FIG. 6 shows that the actual temperatures are rather close to the estimated temperatures by the zone-wise ambience model.

[00116] FIG. 7 is a graph showing a comparison of measured and estimated values of CO₂ concentration with the zone-wise ambience model with constraint (4), according to various embodiments of the present disclosure. Assume that the CO₂ generation rate $B_i(k)$ is constant when the zone occupancy status is unchanged. Graph 701 represents the measured CO₂ concentration data and graph 702 represents the estimated CO₂ concentration data by the zone-wise ambience model with constraint (4). FIG. 7 shows that the measured CO₂ concentration data are close to the estimated CO₂ concentration data by the zone-wise ambience model.

[00117] FIG. 8 is a graph 801 showing experimental results of Stage three 430. The graph 801 depicts a convergence curve for 100 zones. The proposed metaheuristic algorithm may

converge to a sufficiently good results within a small number of iterations in a more efficient and effective manner.

[00118] FIG. 9 is a block diagram showing an example electronic device 900, according to an embodiment of the present disclosure. The electronic device 900 may be a laptop
5 computer, a desktop computer, a tablet computer, an automobile computer, a smart phone, a personal digital assistant, a server, or other electronic devices capable of running computer applications. In some embodiments, the electronic device 900 includes a processor 902, an input/output (I/O) module 904, memory 906, a power unit 908, and one or more network interfaces 910. The electronic device 900 can include additional components. In some
10 embodiments, the processor 902, input/output (I/O) module 904, memory 906, power unit 908, and the network interface(s) 910 are housed together in a common housing or other assembly.

[00119] The processor 902 can execute instructions, for example, to generate output data based on data inputs. The instructions can include programs, codes, scripts, modules, or
15 other types of data stored in memory (e.g., memory 906). Additionally or alternatively, the instructions can be encoded as pre-programmed or re-programmable logic circuits, logic gates, or other types of hardware or firmware components or modules. The processor 902 may be, or may include, a multicore processor having a plurality of cores, and each such core may have an independent power domain and can be configured to enter and exit
20 different operating or performance states based on workload. Additionally or alternatively, the processor 902 may be, or may include, a general-purpose microprocessor, as a specialized co-processor or another type of data processing apparatus. In some cases, the processor 902 performs high-level operation of the electronic device 900. For example, the processor 902 may be configured to execute or interpret software, scripts, programs,
25 functions, executables, or other instructions stored in the memory 906.

[00120] The example I/O module 904 may include a mouse, keypad, touch screen, scanner, optical reader, and/or stylus (or other input device(s)) through which a user of the electronic device 900 may provide input to the electronic device 900, and may also include one or more audio speakers for providing audio output and a video display device for providing textual, audiovisual, and/or graphical output.

[00121] The example memory 906 may include computer-readable storage media, for example, a volatile memory device, a non-volatile memory device, or both. The memory 906 may include one or more read-only memory devices, random-access memory devices, buffer memory devices, or a combination of these and other types of memory devices. In some instances, one or more components of the memory can be integrated or otherwise associated with another component of the electronic device 900. The memory 906 may store instructions that are executable by the processor 902. In some examples, the memory 906 may store instructions for an operating system 912 and for application programs 914. The memory 906 may also store a database 916.

[00122] The example power unit 908 provides power to the other components of the electronic device 900. For example, the other components may operate based on electrical power provided by the power unit 908 through a voltage bus or other connection. In some embodiments, the power unit 908 includes a battery or a battery system, for example, a rechargeable battery. In some embodiments, the power unit 908 includes an adapter (e.g., an AC adapter) that receives an external power signal (from an external source) and converts the external power signal to an internal power signal conditioned for a component of the electronic device 900. The power unit 908 may include other components or operate in another manner.

[00123] The electronic device 900 may be configured to operate in a wireless, wired, or cloud network environment (or a combination thereof). In some embodiments, the electronic

device 900 can access the network using the network interface(s) 910. The network interface(s) 910 can include one or more adapters, modems, connectors, sockets, terminals, ports, slots, and the like. The wireless network that the electronic device 900 accesses may operate, for example, according to a wireless network standard or another type of wireless communication protocol. For example, the wireless network may be configured to operate as a Wireless Local Area Network (WLAN), a Personal Area Network (PAN), a metropolitan area network (MAN), or another type of wireless network. Examples of WLANs include networks configured to operate according to one or more of the 802.11 family of standards developed by IEEE (e.g., Wi-Fi networks), and others. Examples of PANs include networks that operate according to short-range communication standards (e.g., BLUETOOTH®, Near Field Communication (NFC), ZigBee), millimeter wave communications, and others. The wired network that the electronic device 900 accesses may, for example, include Ethernet, SONET, circuit-switched networks (e.g., using components such as SS7, cable, and the like), and others.

15 **[00124]** Some of the subject matter and operations described in this specification can be implemented in digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. Some of the subject matter described in this specification can be implemented as one or more computer programs, i.e., one or more

20 modules of computer program instructions, encoded on a computer storage medium for execution by, or to control the operation of, data-processing apparatus. A computer storage medium can be, or can be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a

25 propagated signal, a computer storage medium can be a source or destination of computer

program instructions encoded in an artificially generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

[00125] Some of the operations described in this specification can be implemented as
5 operations performed by a data processing apparatus on data stored on one or more computer-readable storage devices or received from other sources.

[00126] The term “data processing apparatus” encompasses all kinds of apparatus, devices, and machines for processing data, including by way of example a programmable processor, a computer, a system on a chip, or multiple ones, or combinations, of the
10 foregoing. The apparatus can include special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit). The apparatus can also include, in addition to hardware, code that creates an execution environment for the computer program in question, e.g., code that constitutes processor firmware, a protocol stack, a database management system, an operating system, a cross-platform runtime
15 environment, a virtual machine, or a combination of one or more of them.

[00127] A computer program (also known as a program, software, software application, script, or code) can be written in any form of programming language, including compiled or interpreted languages, declarative or procedural languages, and it can be deployed in any form, including as a stand-alone program or as a module, component, subroutine, object, or
20 other unit suitable for use in a computing environment. A computer program may, but need not, correspond to a file in a file system. A program can be stored in a portion of a file that holds other programs or data (e.g., one or more scripts stored in a markup language document), in a single file dedicated to the program, or in multiple coordinated files (e.g., files that store one or more modules, sub programs, or portions of code). A computer
25 program can be deployed to be executed on one computer or on multiple computers that are

located at one site or distributed across multiple sites and interconnected by a communication network.

[00128] Some of the processes and logic flows described in this specification can be performed by one or more programmable processors executing one or more computer
5 programs to perform actions by operating on input data and generating output. The processes and logic flows can also be performed by, and apparatus can also be implemented as, special purpose logic circuitry, e.g., an FPGA (field programmable gate array) or an ASIC (application specific integrated circuit).

[00129] While this specification contains many details, these should not be understood
10 as limitations on the scope of what may be claimed, but rather as descriptions of features specific to particular examples. Certain features that are described in this specification or shown in the drawings in the context of separate embodiments can also be combined. Conversely, various features that are described or shown in the context of a single embodiment can also be implemented in multiple embodiments separately or in any suitable
15 sub-combination.

[00130] Similarly, while operations are depicted in the drawings in a particular order, this should not be understood as requiring that such operations be performed in the particular order shown or in sequential order, or that all illustrated operations be performed, to achieve desirable results. In certain circumstances, multitasking and parallel processing may be
20 advantageous. Moreover, the separation of various system components in the embodiments described above should not be understood as requiring such separation in all embodiments, and it should be understood that the described program components and systems can generally be integrated together in a single product or packaged into multiple products.

[00131] A number of embodiments have been described. Nevertheless, it will be understood that various modifications can be made. Accordingly, other embodiments are within the scope of the following claims.

CLAIMS

What is claimed is:

1. A method for scheduling a heating, ventilation and air-conditioning (HVAC) system, wherein the HVAC system comprises an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, and the at least one AHU is configured to serve a plurality of zones, the method comprising:

obtaining zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for the plurality of zones, the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points;

obtaining conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air; and

determining, for the at least one AHU and for a prediction horizon, a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-points for the plurality of zones.

2. The method of claim 1, wherein the conditioned air quality indicator is determined by an air quality indicator of the return air, an air quality indicator of the fresh air and the return air ratio.

3. The method of claim 1 or claim 2, wherein the zone air quality indicator includes zone carbon dioxide (CO₂) concentration data, wherein the zone carbon dioxide (CO₂) concentration data at a succeeding time period within the prediction horizon is determined

by a carbon dioxide (CO₂) concentration dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, carbon dioxide (CO₂) generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

4. The method of any of claims 1 to 3, wherein the zone temperature of a succeeding time period is defined as a temperature linear function of the zone temperature of a present time period within the prediction horizon, a zone air conditioning load, a mass flow rate of conditioned air supply in a respective zone of the plurality of zones and the conditioned air temperature.

5. The method of any of claims 1 to 4, wherein the at least one AHU comprises a damper opening configured to vary the return air ratio by adjusting positions of the damper opening.

6. The method of claim 5, further comprising:
determining an average return air ratio across the positions of the damper opening,
and determining differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.

7. The method of claim 6, further comprising:
setting a lower bound and an upper bound for an air conditioning load associated with the at least one AHU,
wherein the lower bound is set when the return air ratio is at a maximum and the upper bound is set when the return air ratio is zero,

wherein the air conditioning load is set between the lower bound and the upper bound.

8. The method of claim 7, further comprising:

(i) obtaining a parameter relating to a coefficient of performance of the air conditioning plant;

(ii) determining the parameter relating to the coefficient of performance of the air conditioning plant to be a first parameter if the air conditioning load associated with the at least one AHU is less than or equal to a first predetermined threshold;

(iii) determining the parameter relating to the coefficient of performance of the air conditioning plant to be a second parameter if the air conditioning load associated with the at least one AHU is less than or equal to a second predetermined threshold and greater than or equal to the first predetermined threshold; and

(iv) continuing step as described in (iii) until the air conditioning load associated with the at least one AHU is greater than a last predetermined threshold, and determining the parameter relating to the coefficient of performance of the air conditioning plant to be a last parameter.

9. The method of claim 8, further comprising:

optimizing the return air ratio based on an optimization function of the determined parameter relating to the coefficient of performance of the air conditioning plant and the differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.

10. The method of claim 9, further comprising:

mapping a conditioned air coupling based on a zone damper opening for the plurality of zones and a fan supply air pressure for the at least one AHU to a mass flow rate of conditioned air supply for the plurality of zones.

11. The method of claim 10, further comprising:

communicating the optimized return air ratio to a scheduler;

receiving, at the scheduler, the optimized return air ratio and energy efficiency data of the air conditioning plant;

balancing the optimized return air ratio against the parameter relating to the coefficient of performance of the air conditioning plant for a subsequent time period;

calculating an air supply strategy based on the balancing, the air supply strategy comprising a conditioned air supply allocation for the plurality of zones in the subsequent time period to minimise energy consumption of the air conditioning plant while aiming to meet the zone set-points; and

delivering the air supply strategy to the plurality of zones.

12. A system for scheduling a heating, ventilation and air-conditioning (HVAC) system, wherein the HVAC system comprises an air conditioning plant, at least one air handling unit (AHU) in connection with the air conditioning plant, the at least one AHU is configured to serve a plurality of zones, the system comprising:

a zone module configured to obtain zone environmental information including a zone temperature, a zone air quality indicator and zone set-points for the plurality of zones, the zone set-points for the plurality of zones comprising zone temperature set-points and zone air quality set-points;

an input module configured to obtain conditioned air temperature and conditioned air quality indicator of conditioned air associated with the at least one AHU and fresh air temperature of fresh air configured to mix with return air of the conditioned air to form pre-conditioned air; and

a scheduler, for the at least one AHU and for a prediction horizon, configured to determine a minimum conditioned air supply rate and a return air ratio based on a conditioned air function of parameters including the zone temperature, the conditioned air temperature, the fresh air temperature, the zone air quality indicator and the conditioned air quality indicator so as to collectively meet the zone set-points for the plurality of zones.

13. The system of claim 12, wherein the conditioned air quality indicator is determined by an air quality indicator of the return air, an air quality indicator of the fresh air and the return air ratio.

14. The system of claim 12 or claim 13, wherein the zone air quality indicator includes zone carbon dioxide (CO₂) concentration data, wherein the zone carbon dioxide (CO₂) concentration data at a succeeding time period within the prediction horizon is determined by a carbon dioxide (CO₂) concentration dynamic model as a multi-component function including a plurality of components relating to zone parameters selected from a group of air volume, air density, carbon dioxide (CO₂) generation rate of occupant(s) and/or equipment(s) of a respective zone of the plurality of zones.

15. The system of any of claims 12 to 14, wherein the zone temperature of a succeeding time period is defined as a temperature linear function of the zone temperature of a present time period within the prediction horizon, a zone air conditioning load, a mass flow rate of

conditioned air supply in a respective zone of the plurality of zones and the conditioned air temperature.

16. The system of any of claims 12 to 15, wherein the at least one AHU comprises a damper opening configured to vary the return air ratio by adjusting positions of the damper opening.

17. The system of claim 16, wherein the scheduler is further configured to:
determine an average return air ratio across the positions of the damper opening and
determining differences between the return air ratio when the damper opening is at each of
the positions and the average return air ratio.

18. The system of claim 17, wherein the scheduler is further configured to:
set a lower bound and an upper bound for an air conditioning load associated with
the at least one AHU,
wherein the lower bound is set when the return air ratio is at a maximum and the
upper bound is set when the return air ratio is zero,
wherein the air conditioning load is set between the lower bound and the upper
bound.

19. The system of claim 18,
wherein the input module is further configured to:
(i) obtain a parameter relating to a coefficient of performance of the air conditioning
plant;
wherein the scheduler is further configured to:

(ii) determine the parameter relating to the coefficient of performance of the air conditioning plant to be a first parameter if the air conditioning load associated with the at least one AHU is less than or equal to a first predetermined threshold;

(iii) determine the parameter relating to the coefficient of performance of the air conditioning plant to be a second parameter if the air conditioning load associated with the at least one AHU is less than or equal to a second predetermined threshold and greater than or equal to the first predetermined threshold; and

(iv) continue step as described in (iii) until the air conditioning load associated with the at least one AHU is greater than a last predetermined threshold, and determine the parameter relating to the coefficient of performance of the air conditioning plant to be a last parameter.

20. The system of claim 19, wherein the scheduler is further configured to:

optimize the return air ratio based on an optimization function of the determined parameter relating to the coefficient of performance of the air conditioning plant and the differences between the return air ratio when the damper opening is at each of the positions and the average return air ratio.