



2016 International Electrical Engineering Congress, iEECON2016, 2-4 March 2016, Chiang Mai, Thailand

## Development of Coordination Control for Multiple Rooftop Units

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### Abstract

Rooftop Units (RTUs) have been widely applied in providing space heating and cooling for commercial buildings. In total, they serve over 60% of the commercial building floor space in the U.S. Even through the current control approaches of a RTU can maintain the zone temperature corresponding to a set point temperature, it performs inefficiently due to several factors such as limited sensing capability, non-coordinated local control, inherent oversizing effects and so on. In addition to unnecessary power consumptions, the current control and operation technology on RTUs also lead to the space humidity problem, equipment efficiency degradation, and premature failure. To solve aforementioned problems and enhance the overall system performance, this paper presents the development of a coordination control technique for improving the system operations of multiple RTUs used in light commercial buildings with an open space. In the control algorithm, simplified building models were developed to potentially estimate the instantaneous building load. Utilizing this model-based technique, sequence control strategy is designed to automatically select suitable mode operations of a RTU including economizing, heating, cooling and ventilation mode while synchronizing with the supply fan control and damper operations. Using a developed building simulation platform implemented on Matlab software, the developed coordination control is applied in reducing energy penalty caused by an inherent oversizing problem on multiple RTUs. With the findings, the control algorithm can be further used as a soft-repair for temporally fixing faulty operations and improper commissioning of multiple RTUs such as excessive or insufficient air flow, outdoor air leakage, stuck dampers and simultaneous heating and cooling (RTU fighting).

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Peer-review under responsibility of the Organizing Committee of iEECON2016

**Keywords:** Coordination Control; HVAC; Instantaneous Load; RTU; Fault Detection and Diagnosis;

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## 1. Introduction

As one of typical heating, ventilation and air-conditioning (HVAC) equipment, rooftop units (RTUs) have been intensively used in commercial buildings; they consumed around 60% of total energy to provide both cooling and heating systems for light commercial buildings with an open space in the U.S [1]. Specifically, multiple RTUs are commonly designed to maintain thermal comfort in multi- zone layout for low-rise cubicle offices or big-box retail stores. As a result, proper sizing and operations of RTUs lead to significant energy savings [2]. Although the current individual control methods of RTUs, such as a multi-speed fan control, demand-controlled ventilation and multi-stage compressor control, works fine in maintaining the thermal comfort of a conditioned space, they waste much energy due to RTU fighting, non-coordinated local control, and inherent oversizing effects [3]. These uncoordinated control approaches also decrease the life cycle of equipment, affects the indoor humidity and can cause unsuitable interaction between RTUs and the refrigeration system in supermarkets. Fundamentally, the present retrofitting solutions are still individual control without embedded optimizing and solving function the inter-zone interactions between zones.

## 2. Model development

The simplified model of the coordination control was developed based on steady-state heat balance equations composing of: a balance temperature, cooling and heating set-point, outdoor air temperature and envelop load coefficient of an enclosed structure. The developed model was tested and validated through a building simulation platform [4]. The model was derived based on the assumptions which are: 1) a few windows are installed in retail stores. As a result, radiation term is neglected for the simplified instantaneous load model; 2) the model uses the two load points to construct a linearized curve including: the first point is at balance temperature ( $T_b$ ) that mechanical cooling is not required or it is no load condition. The second point is based on peak heating or cooling condition when outdoor temperature is maximum; 3) the cooling load is performing at RTU design capacity in terms of cooling set-point ( $T_{sp,c}$ ), whereas the heating load performs design capacity at heating set-point ( $T_{sp,h}$ ); 4) generated load, composes of internal loads from occupancy, lighting and plug equipment; and 5) Although the building structure may heat up and cool down during a day, the difference in energy between the start and end is small relative to the total energy. As a result, the change rate of energy storage is neglected. With the assumptions, the instantaneous heating load and cooling are defined as follows:

$$\dot{Q}_h = k_{env}(T_b - T_{amb}) \quad (1)$$

$$\dot{Q}_c = k_{env}(T_{amb} - T_b - (T_{sp,c} - T_{sp,h})) \quad (2)$$

, where  $k_{env}$  is the building envelop load coefficient, and  $T_{amb}$  is the ambient temperature.

## 3. Coordination control algorithm for optimizing energy consumptions of oversized RTUs

The characteristics of oversizing issue are observed from runtime fraction (RTF) and RTU operations [2]. The average RTF of some RTUs is much smaller than 1.00 at the design temperature conditions; it means oversizing issue being very severe. As a result, the on-time period of the RTUs in this case should be adjusted longer while satisfying thermal comfort of the zones. For the routine operations in terms of interactions among adjacent RTUs, the operations of RTUs are not synchronized; each one is controlled by the thermostat. With the interactions in terms of good sides, the thermal comfort of a zone could be satisfied even if the RTU associated with that zone operates occasionally. As a consequence, it is not essential to operate each RTU simultaneously so as to satisfy building comfort. The coordination control algorithm can be designed as tabulated in Table 1. **In step 1**, since each RTU is over designed, a satisfied minimum airflow rate is required to be computed by Eq. 3 by selecting the maximum value from  $\dot{V}_c$ ,  $\dot{V}_h$  or  $\dot{V}_v$  in the whole open space of a light commercial building such as a retail store as shown in Fig. 1; the simplified instantaneous models in Eq. 1 and 2 are used to compute total actual load, and then are converted into  $\dot{V}_c$  and  $\dot{V}_h$  in Eq. 5 and 6. Meanwhile,  $\dot{V}_v$  can be determined from Eq. 4. **In step 2**, applying Eq. 7

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