ACTIVE LOADS IN OFFICE BUILDINGS AS A DEMAND SIDE RESOURCE TOWARDS THE SMART GRID

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ABSTRACT

A key characteristic of the smart grid is its multi-directional flow of power and information and hence transformation of the demand side management to demand side integration philosophy at low level voltage. This implies that buildings must also provide service to the electrical smart grid in as much as it is also serviced by the latter. Consequently the phenomenon of active loads has become evident in form of using Building Services components like cooling machines, heat pumps and others to service the utility grid. Taking cue from tests performed in the United States and the United Kingdom, experiments were conducted at an existing office building in Breda, Netherlands. Additional metering was installed to be able to measure rather detailed the energy flows within the building. The potential and possible effects on recommended comfort levels were investigated in this case study building. The electrical steam humidifier and the air handlings units were used as an active load to see to what extent they could support the Smart Grid. The effects of the different contributions towards the Smart Grid were determined. Specifically the steam humidifier and ventilators were operated on modulated mode and reduced capacity all within corresponding comfort conditions monitored. Results indicated that whereas potentials existed for such uses, care had to be taken to determine critical operational boundaries of the equipment. Depending on the level of responsiveness and the control strategy, the main energy uses of the building, the steam humidifier and air handlings unit, can be used as active loads.

Keywords: Active loads, SmartGrid

INTRODUCTION

The subject of energy has become increasingly contentious with current strict emissions targets for the future [CIBSE 2012]. Recently these environmental issues along with the rapid growing surge in fuel cost have drawn particular attention to distributed renewable energy resources (DRES) [Brahman et al 2015]. With the expected increase of renewable generated energy with its stochastic behaviour in the total generated energy mix, the energy management of the grid will change in the future. This forms a challenge for the grid stability and as well as efficiency, reliability, availability, controllability and security. As commercial office buildings are more sophisticated and better equipped for more flexible control and actuation possibilities, dynamic control of building's Heating, Ventilation and Air-Conditioning (HVAC) systems in relation to actual perceived occupancy comfort presents an opportunity for more efficient use of these systems as active loads towards the Smart Grid. In the Netherlands there are around 78.000 office buildings which use in total around 225 PJ/year compared to around 370 PJ/year for households in the Netherlands [RVO 2014]. So overall the energy use of offices is around 60% of the total energy use of the households, so quite substantial. The energy consumption of office buildings is increasing slightly, despite the 2020 targets set by the EU, which calls for a 20% reduction in energy use by the year 2020. Therefore our focus was on the energy efficiency as well as the possible use of active loads in office buildings as a demand side resource towards the Smart Grid.

METHOD

Buildings offer unexpected possibilities. Without knowing people sit 90% of their time in a vast energy storage device. The heat or cold storage in buildings is an enormous resource for providing regulation services [Cui et al 2015]. Buildings can play an important role in DR programs by actively reducing their power consumption during peak hours. The heating, ventilation and air conditioning (HVAC) systems, which account for 50% or more of the whole building power consumption on average, are the main contributor for demand response in buildings. HVAC systems can be an excellent demand response resource to supply ancillary reserves [Motegi et al 2005]; HVAC systems contribute the largest portion of consumption in buildings. And the operation of HVAC systems can be curtailed or the equipment can be partially shut down without producing serious impact on building occupants [Eto et al 2007]. This DR does not have ramping time, minimum on or off time limits that constrain many generators {Cui 2015}. The curtailment can be nearly instantaneous, which is much faster than the 10 min allowed for generators to fully respond [Kirby et al 2008].

Two main categories of DR strategies for HVAC systems were summarized by Watson et al. [2006], which are global temperature adjustment plus system adjustment. Global temperature adjustment is done by increasing building zone temperature set-points during the active intervention. System adjustment includes duct static pressure setpoint reduction, fan quantity
Hao et al. [2012] described how ancillary services could be achieved by reducing the power consumption of HVAC systems. The numerical experiments showed that for this HVAC system, 15% of fan power capacity could be provided for regulation, while maintaining indoor temperature deviation to no more than ±0.2 °C. Based on these results, they concluded that the HVAC systems in all the commercial buildings in the U.S. can provide about 70% of the current regulation capacity needed in the United States.

Energy management system (EMS) are a promising mean to optimally coordinate all generation, consumption and energy storage resources of buildings connected to the SG both economic and technical facets [Brahman et al 2015] Chen et al [2011] presented a smart EMS, which incorporates a power forecasting module, ESS, and an optimization module to achieve a great coordination between power production of DRES units and SG [Brahman et al 2015].

At the core of dynamic energy management is the concept of active load. Active loads are unique in their ability to reliably deliver resources to the power system whilst also maintaining quality primary service to end users [Callaway and Hiskens 2011] In essence, this can be any load that has a form of thermal storage capacity such as HVAC systems, refrigeration and driers [Trudnowsk et al 2006]. To be relevant, active loads must be both competitive in comparison to generators that provide the same service whilst also ensuring that they have an almost negligible effect on quality of service rendered to the end user [Callaway and Hiskens 2011]. A number of advantages make active loads preferable. However, these differ from one piece of equipment to the other and are specific to both equipment and operational boundary conditions; past studies have not fully specified operational boundaries or quantified process specific advantages associated with active load concept [Pratt 2004]. As part of a wider experiment in building control within SG some experiments with active load based dynamic energy management were conducted in the Netherlands to evaluate the potential and operational boundaries for using HVAC-systems as active loads as demand resources to the power system.

CASE STUDY OFFICE BUILDING

The Kropman Breda office was built in 1992 and revised in 2009. It is a three story high building with around 1400 m² floor space and 50 employees. The office building is connected to a mid-voltage transformer station by two main connections and main power systems connected were measured. Fig. 1 shows the major electricity load groups of the office building: a mechanical ventilation system with heat recovery wheel (no recirculation of air); central cooling; electrical steam humidifier; heating by ventilation and two radiator groups.

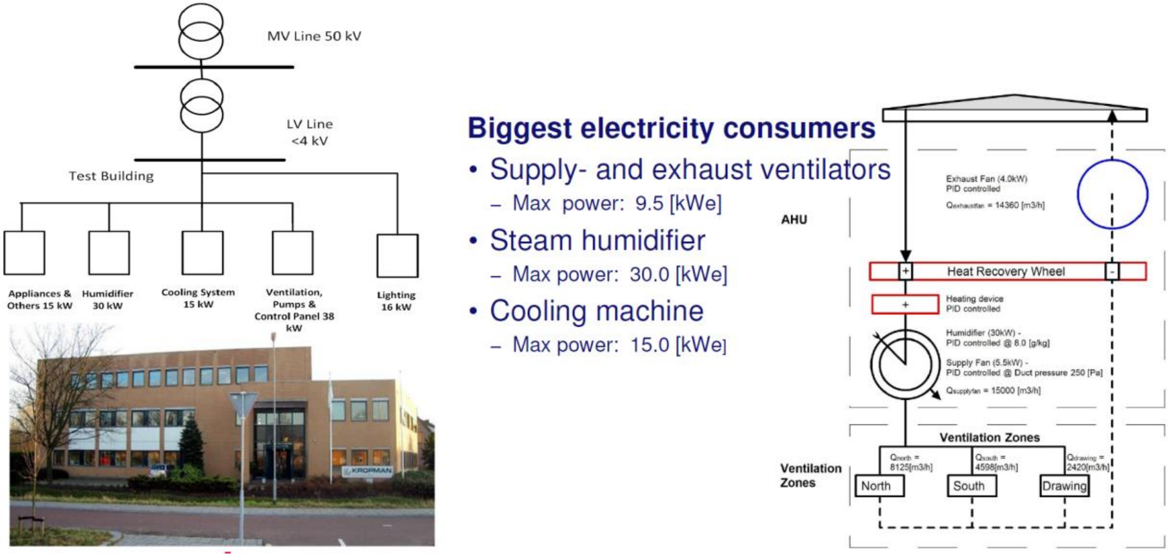

Figure 1. The electrical connections from Mid Voltage grid to building and its major electricity consumers.

The first floor, see Fig. 2, was chosen for more detailed measurements because it was the most regularly occupied floor. In each room the temperature, CO_2 concentration, humidity and average airspeeds were measured during the project in accordance to ISO 7726 [ISO 1998] and the ASHRAE Performance Measurement Protocol [ASHRAE 2010].

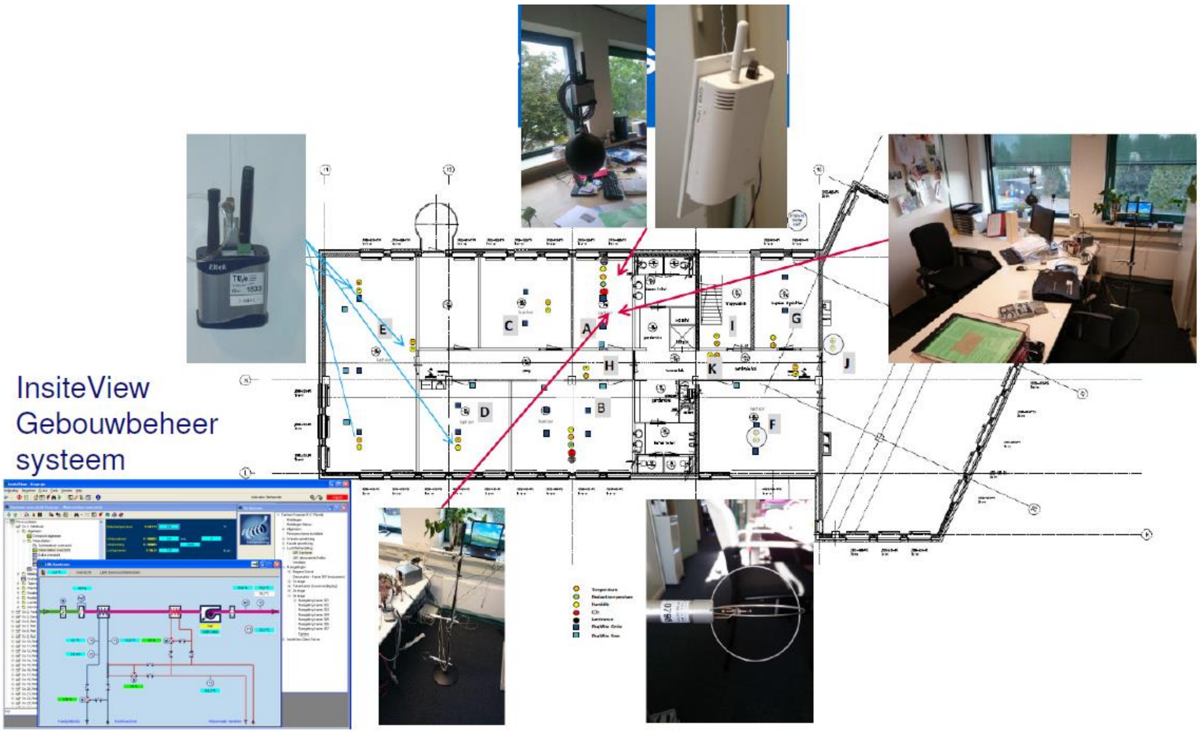

Figure 2. Test case office building Kropman Breda

The biggest controllable electrical energy consumer is the Air Handling Unit during wintertime with its steam humidifier, see Fig. 3. The installed VAPAC VP30 power consumption peaks at 30 kW.

Figure 3. Air Handling Unit and steam pipe

The biggest controllable electrical energy consumers in the AHU during wintertime are the supply and exhaust fans and the steam humidifier with an installed capacity of 5.5, 4.0 and 30 [kW]. The actual power usage is usually lower than the maximum rated power. For both fans together the actual consumption during normal operations is 4 – 5 [kW]. The humidifier operates at start in the early morning near its peak to 28 [kW], but then dependent on the out- and indoor conditions the power consumption reduces from usually 6 – 20 [kW].Two experiments were done for active load purposes: Experiment I: during the steam humidifier power reduction interval of 15 minutes, approx. 14 [kW] power was saved, during the 30 minutes interval 9 – 14 [kW] and during the 60 minutes interval about 12 [kW] was saved. To avoid peaks after switching to normal set point, the interval set point should be slightly higher than the minimum demand of the humidifier. Experiment II: during the fan power reduction interval of 15 and 30 minutes a total of 7 [kW] was saved, at the 60 minute interval 6 – 7 [kW] was saved.

RESULTS

The energy reduction statement is tested by two experiments namely: Exp. I: steam humidifier power reduction and Exp.2: supply- and exhaust fan power reduction.
The experiment I took place at the 20th of December. The power savings in [kW] during this experiment day were at interval time: I (15min), II (30min), III (60min): 14, 9 – 14 & 12. This energy saving is generated by changing the humidifier absolute humidity set point from 8.0 to 6.0 [g/kg], at 21.5 [˚C], this correspond respectively to a supplied RH of 51 [%] and 37.5 [%], see Fig. 4.

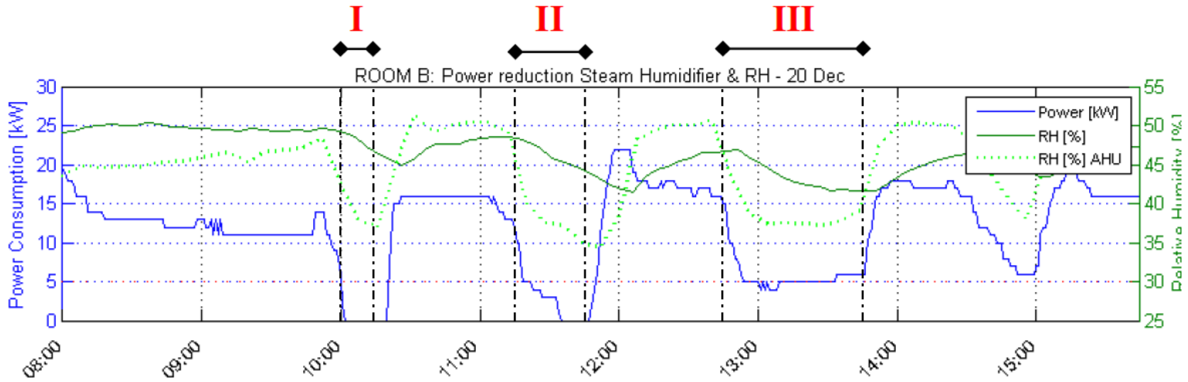

Figure 4. Results room B relative humidity, relative humidity AHU and power consumption

At the second experiment the fan supply- and exhaust rates are reduced to 25% of the normal conditions. This results in 2 [kW] energy savings from the fans for all three interval times, but at the same moment the power consumption of the steam humidifier also decreased with 5 [kW]. The relative humidity concentration in all rooms remains stable since the set point of the absolute humidity stays 8.0 [g/kg]. The indoor carbon dioxide concentration [ppm] did not exceed the comfort boundary condition of 800 [ppm]. Approximately 7 [kW] is saved during the 14th of January with 25% flow reduction. This is a proper flexible energy saving source derived by the AHU, without exceeding set comfort boundary conditions.

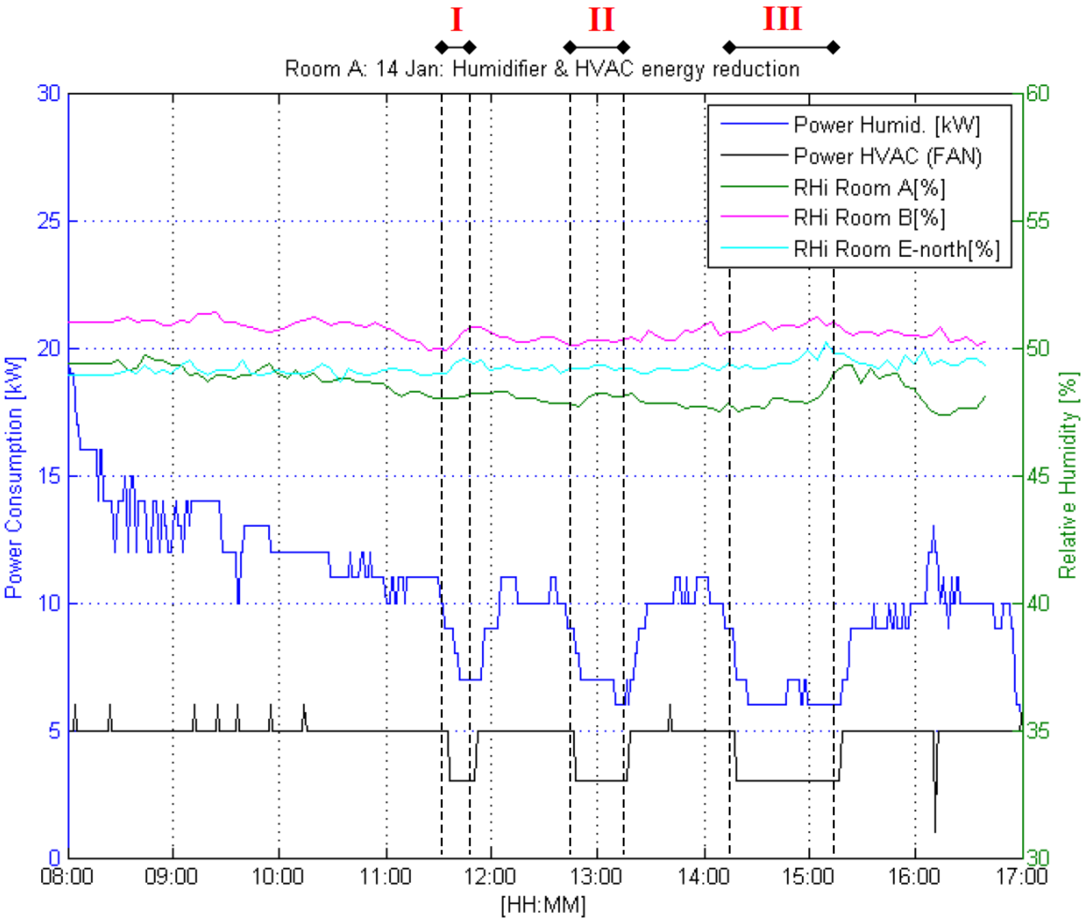

Figure 5. Energy consumption fans and humidifier during experiment II, interval times are black dashed

Below table 1 shows the potential yearly energy savings based on the data gathered during the experiments.

Table 1: Yearly energy savings with energy data found at 3rd interval experiment I & II

	Expected operation time during a year:	*Expected saving:*
Exp 1. Humidifier	1392 hours	13920 [kWh] (10kW saving /h)
Exp 2. Fans	2739 hours	5487 [kWh] (2kW saving /h)
Exp 2. Side effect fan reduction → humidifier power reduction	1392 hours	6960 [kWh] (5kW saving /h)

DISCUSSION AND CONCLUSIONS

The energy saving and active load experiments were only done at two particular winter days to show energy savings from the AHU. More test days are preferred to understand the energy reduction at different outdoor conditions. Short time (15 – 60 minutes) energy savings from the (AHU) steam humidifier and fans as active loads can be derived within comfort boundaries during wintertime. This energy saving regulation could be used for future smart-grid integration. The humidifier is slow responding because of the control time delay, this can be adjusted to faster responding times for better interaction to the grid. The fan reduction has a fast responding time, since a fast time delay is set in the BMS control. It has a good potential for future frequency demand control service. Active loads in office buildings can offer as a demand side resource benefits towards the Smart Grid.

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