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Operational performance of passive multi-family buildings: commissioning with regard to ventilation and indoor climate

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Abstract

The first year commissioning activities in 4 multi-family buildings from a zero-carbon neighbourhood is presented, with focus on the operation of the ventilation systems, the indoor climate and user acceptance. The key parameters to detect the main system failures are identified and the effect of the detected defects and failures on the energy performance of the dwellings is explored using dynamic simulations and monitoring data. It is concluded that commissioning of the building systems during occupancy is a vital part of the operational lifetime of a building project in order to achieve the high building performance targets in reality.

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1. Introduction

In the context of the EU FP7 CONCERTO ECO-Life project, a zero-carbon social housing neighbourhood *Venning* is built in Kortrijk (Belgium). One part of the neighbourhood consists of four new multi-family buildings including 82 apartments in total. The building design was guided by the passive house standards: the building envelope is highly insulated with special attention to the air tightness and solar shading. The buildings are equipped with collective mechanical ventilation systems with heat recovery and the neighbourhoods' low-temperature biomass-fuelled district heating grid provides the dwellings with heat for space heating, preheating of the ventilation supply air and domestic hot water. In July 2013, these first buildings were finished and gradually occupied.

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An important goal of the ECO-Life project - "*Sustainable zero-carbon ECO-town developments improving quality of life across EU*" - is to reach the high energy performance targets and quality of life during operation and occupancy. In order to evaluate the actual operation of the buildings and systems, commissioning activities were executed not only during the construction works, but continued during the first years of occupancy [1,2]. They include quality assurances tests, such as pressurisation tests and ventilation flow rate measurements, automated monitoring of the energy flows, indoor and outdoor climate and a questionnaire to a sample of the occupants. The available data and information is used to analyse and evaluate the operation of the different parts of the ventilation systems and their influence on the indoor climate. In view of a faster or automated fault detection during operation, it is investigated whether the detected problems could also be recognised using only monitoring data. Finally, some exemplary apartments are modelled and the effect of the identified defects on the heat demand and indoor temperature is investigated using dynamic simulations.

2. Operation of the central air handling units

The four multi-family buildings are ventilated through three collective ventilation systems (one or two per building), so there are three air handling units (AHU A, AHU B/C and AHU D). From the viewpoint of energy performance and indoor air quality, the main operational parameters of the air handling units are the operation of the heat exchangers, for recovery of the heat from the extraction air to preheat the supply air, the operation of the fans, that should provide correct ventilation flow, and the electricity needed to perform these tasks.

2.1. Heat exchanger

The heat exchanger is a rotary air-to-air enthalpy wheel, in which both sensible and latent heat transfer appear. Figure 1 shows the monitored supply, extract, fresh and exhaust air temperatures in two of the AHU's. A most remarkable observation is that in AHU A in February 2014, the fresh air temperature and the supply air temperature are very close to one another, as well as the extract and exhaust air temperatures (Fig. 1(a)). Apparently the heat exchanger didn't work and thus the heat recovery potential of the system was not utilised. The failure was remediated, and Fig. 1(c) confirms that in August 2014 the ventilation supply air was preheated indeed.

The effectiveness of the heat exchanger is here defined as the proportion of the real temperature variation to the maximum temperature variation over the heat exchanger. The effectiveness can be calculated for either the supply or the extract air of the system, and, assuming equal ventilation flow rates, supply and extract effectiveness should be equal. For the heat exchanger in AHU B/C the effectiveness in winter is around 85% for both sensible and latent heat, according to the product specifications. From the monitoring a supply effectiveness of about 90% is estimated and an extract effectiveness of 62%. Based on the specific moisture content of the flows, the latent effectiveness can also be calculated. And also here the difference between supply and extract effectiveness, 92% vs. 38% is substantial. Possible explanations are a deviation between the measured temperature of a flow and its actual temperature, for example as a result of air leakages between different flows in the system, infiltration of air in the surroundings of the unit, or inaccuracy of the temperature measurements. The likelihood of the possible explanations is investigated by Van de Putte [2].

For a continuous follow-up of the most important function of the heat exchanger, that is to ascertain that the heat exchanger is actually working, it is concluded that the key monitoring parameter is the supply air temperature, followed by the fresh air temperature, which could also be estimated by outdoor temperature measurements. If the extract temperature is added to the measurements, or estimated from indoor temperature measurements in the dwellings, the supply effectiveness of the air handling unit can also be calculated. Calculation of the extract effectiveness and secondary deficiencies such as air leakages in the system, require measurement of the exhaust air temperature, and additional measurements of the relative humidity and CO_2 in the air flows.

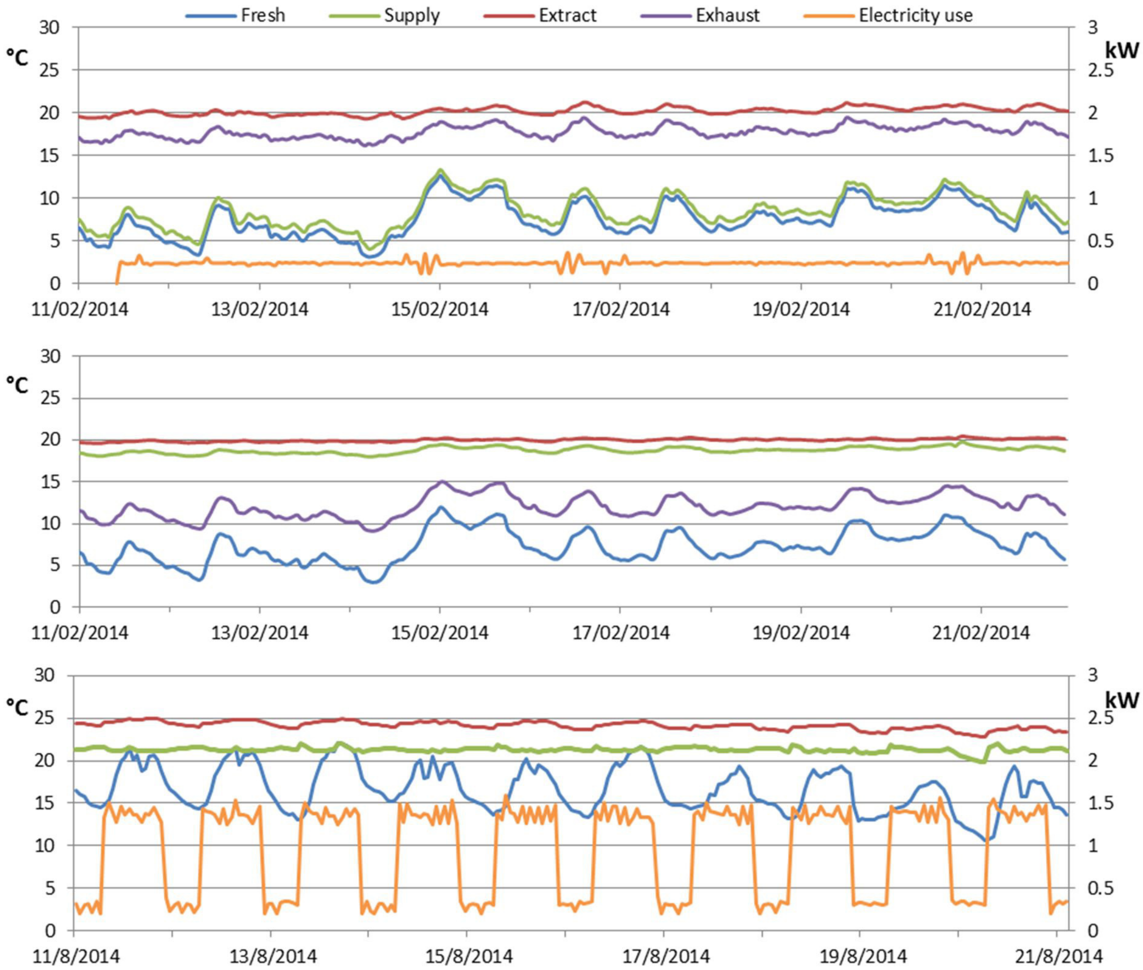

Fig. 1. Temperatures and electricity use in (a) AHU A in February 2014 (b) AHU B/C in February 2014 (c) AHU A in August 2014

2.2. Ventilation flow rate

The ventilation flow rates are entirely controlled in the central air handling unit. There is a constant flow rate for daytime (on average 200 m³/h/apartment) and a fixed night set-back (on average 90 m³/h/apartment). The occupants do not have the possibility to control the ventilation flow rates nor the temperatures, and they are asked not to adjust the ventilation openings. The collective air distribution network is well-insulated and a high level of duct air tightness was obtained, that is class C according to NBN EN 12237. The ventilation flow rates were calibrated by tuning the supply air terminal units in the dwellings at the end of the construction phase.

In February 2014 the actual ventilation flow rates were verified through measurements at the inlets and outlets in a sample of dwellings connected to different AHU's. The results showed that in all these dwellings the flow rates were very low, that is on average only about 30% of the design flow rates. Inspection of the central air handling units revealed that they had been working continuously in the night set-back level, after acoustic complaints by the occupants. Subsequent acoustic measurements in the dwellings indicated that indeed the maximum allowed sound pressure level was significantly exceeded, e.g. measurements of 40 dB(A) instead of the maximum allowed 30 dB(A) in the bedrooms. After installation of acoustic dampers on the main ventilation ducts of the dwellings, the settings of the AHU's were adapted, in order to allow them to provide the design flow rates during daytime.

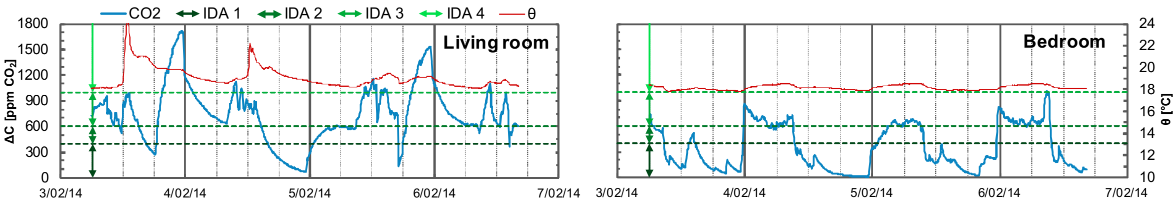

Fig. 2. Measurements of the CO_2-concentration in a dwelling in February 2014

The effect of the reduced ventilation flow rates on the indoor air quality (IAQ) in the dwellings was investigated by use of temporary CO2-measurements in some dwellings. The upper boundary of IDA-class 3 is usually accepted as the minimum admissible IAQ-level in design guidelines and standards, corresponding to <30% of people dissatisfied with the IAQ and to a minimum ventilation flow rate of ca. 22 m^3/h/person. In the case-study dwellings in the neighbourhood, it was found that the IAQ in the rooms was often "acceptable"(IDA3) and even "low"(IDA4) during periods of occupation, even if most of the dwellings in the neighbourhood are occupied by less people than they were designed for. The IAQ in a room typically only reached "average"(IDA2) or "high"(IDA1) levels when it was not or shortly occupied or after opening of the windows. In Fig. 2 this is illustrated for a typical dwelling with 2 bedrooms (designed for 3 occupants), occupied by an elderly couple that is at home most of the time.

During the commissioning process the malfunctioning of the central air handling unit was discovered through manual measurements of the ventilation flow rates in a sample of the dwellings. However, for the purpose of continuous commissioning or real-time follow-up of the operation of the systems, again a more automated procedure is desirable. For this purpose, monitoring of the electricity use of the AHU's is of particular interest. In Fig. 1(a) and (c) the hourly electricity use of AHU A is presented. Before remediation of the system, the hourly electricity use was continuously around 0.25 kWh. After remediation the electricity use demonstrates a clear daily pattern in which periods of reduced energy use during night set-back alternate with day periods with an energy use of about 1.4 kWh per hour. The graphical presentation of the hourly electricity use thus enables to check whether or not the ventilation system is in operation and, after an initial comparison to flow rate measurements in the dwellings, if the ventilation flow rate produced at the central unit is correct. Remark however that it will not visualise changes in the ventilation flow rates at the level of the dwelling, for example due to adjustments of the ventilation openings or duct leaks.

2.3. Estimated energy use of the air handling units

The electricity monitoring data of AHU A enables an estimation of the auxiliary energy needed for the operation of the system. The typical yearly electricity use of the ventilation system is estimated on average 375 kWh/year per dwelling. That is similar to the estimations in the official energy performance calculations in context of the EPBD legislation in Flanders. In 2014, due to the malfunctioning and the subsequent adjustments of the ventilation system, the system will have used only 285 kWh/year/dwelling. The Specific Fan Power is 0.32 (class SFP3).

3. Dwelling air tightness and local HVAC components

Apart from the observations related to the central air handling units, the operation of an HVAC component within the dwelling was also investigated, that is the heating coil. Also the air tightness level of the dwellings is verified.

3.1. Air tightness of the building envelope

In 17 out of 82 dwellings, the blower door test was repeated about one year after the initial test by the contractor and half a year after the start of the occupancy. In the original tests, the n50 air change rate at a pressure difference of 50Pa was between 0.42/h and 0.62/h, or on average 0.53/h. One year later, the results were, between 0.51/h and 0.84/h, or on average 0.71/h, and thus exceed the maximum design value of 0.6/h. On one hand it is known that the results of different blowerdoor tests of the same object can diverge a little, on the other hand it is probable that the air tightness level of the dwellings has decreased in meantime, e.g. due to initial aging [3].

3.2. Operation of the heating coil

Each dwelling is provided with a heating coil, that preheats the supply air coming from the heat exchanger to 19°C if needed. In case the central heat exchanger is inactive, as happened in AHU A and D, fresh air at outdoor temperature reaches the heating coil, which starts to preheat the air as soon as the instantaneous outdoor temperature is below 19°C (a very common situation in Belgium). Thus, the heating coil will partially conceal the defect of the heat exchanger to the occupants. Because however the heating coil has a limited power, the air is heated up with about 8°C, and during cold winter periods an uncomfortable cold jet will be supplied in the dwellings, causing the feeling of draught and augmenting the heating demand to the radiators.

The monitoring data show that the set-point of the heating coil in all dwellings is 21°C instead of the 19°C that was prescribed by the designers. This can be a benefit in terms of thermal comfort for those users that appreciate rather high indoor temperatures, but it is a disadvantage for those who appreciate or accept lower indoor temperatures, in terms of thermal comfort and/or energy use.

4. Effect on the heat demand and temperatures of the dwelling

Besides indoor air quality, acoustic and thermal comfort, the changes and defects in the ventilation systems will influence the heat demand of the dwellings. While heat use monitoring data give insight in the total heat use of a dwelling in real conditions (including real building and system operation, user behaviour and climate), it is hard to distinguish the effects of different operational characteristics. Therefore four representative apartment types are modeled in detail using the dynamic simulation software TRNSYS, and the previously observed adaptations and defects are added to the models one by one, so their respective influence on the heat demand can be identified [2]. The ventilation system is simulated with a heat recovery effectiveness of 60% and the extract temperature equals the flow rate weighted average of the temperatures in the rooms with extraction. Based on the findings from a survey, set-point temperatures of the thermostats between 18 and 27°C were chosen, as well as the option of deactivating the heating, which was the heating strategy in 4 out of 15 surveyed apartments. Since most of the people admitted that they do not adapt the set-point regularly, it was decided to keep the set-point temperature in the dwellings constant. In this initial conditions, the heat demand of the dwellings is around 18kWh/year/m² (GFA) for dwellings with the heaters turned off or with a heating set-point below 21°C, and up to 42 kWh/m²/year for dwellings with a higher set-point temperature and dependent on the dwelling type.

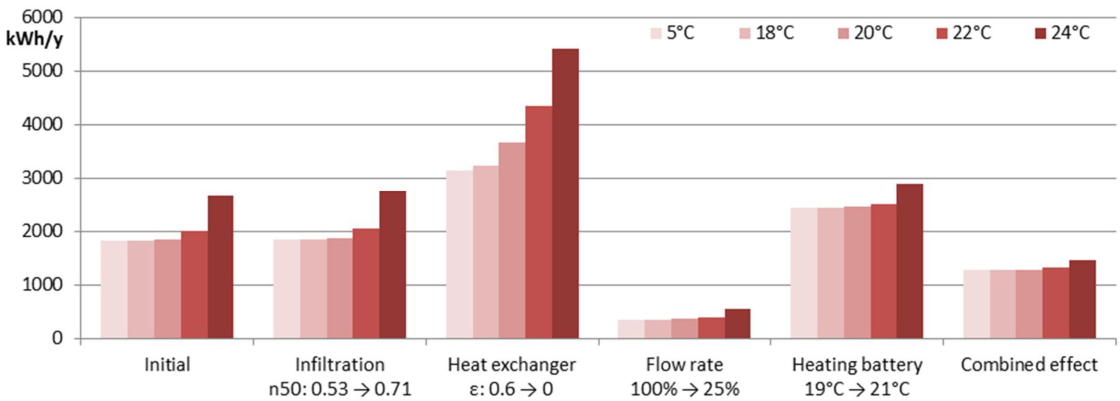

Fig. 3. Effect of defects on the heat demand of dwelling type A for different set-point temperatures

Figure 3 illustrates the effect of the different adaptations and defects on the heat use in an enclosed apartment type with 2 bedrooms. The small decrease in air tightness from 0.53/h to 0.71/h, results indeed in a small increase of only 1-3% of the heat demand of the house. In a next adaptation to the model, the heat exchanger is deactivated. Since now the heating coil has to preheat the fresh air up to 19°C, and the space heating system takes over when the heating coil reaches its full power, the heating demand of the dwelling will increase between 70 and 140% (depending on the type of dwelling and the set-point temperature). When on the contrary the ventilation flow rate is reduced from 100% to about 25%, a reduction of the heating demand of about 80% is seen in comparison to the initial situation. Assuming that the reduction of the ventilation flow rate is not compensated by the opening of windows, the temperature in the living room will augment with a few degrees during winter, but also give rise to serious overheating during summer, when the indoor temperature becomes easily 5°C higher than in a situation with design flow rates. Next, the impact of the higher set-point temperature of the heating coil is observed. In dwellings with a set-point temperature below 21°C, an increase of the set-point from 19° to 21°C causes on average 35% increase in heating demand. A part of the heating demand from the heating system (if activated) will shift towards the heating coil, but also the unheated rooms will now receive a warmer supply flow. Especially in dwellings with a low heating set-point, this setting will lead to unnecessary heat use and possibly to a higher temperature than required.

Finally the combined effect of all previous defects is simulated, imitating the actual operation of the buildings during winter 2013-2014. In comparison to the initial situation, the combination of defects gives rise to a decrease in heating demand of 23 up to 30% and 30 up to 50% in dwellings with a set-point below and above 21°C respectively. The reduction of the ventilation flow rate, which is the only defect that actually introduces a decrease in the heating demand, thus outweighs the influence of the other defects on the total results. Remark that despite the lower total heat demand, still an amount of heat is wasted, since the warm ventilation air is lost and in the same time other energy sources are used to preheat the air in the heating coil. This illustrates the added value and even necessity of an in-depth commissioning of residential buildings and building systems during the occupancy and the danger that lies in assessing the energy performance of a building only by the total energy use measurements.

5. Conclusions

In this paper, the approach and findings of the first year commissioning activities in four high performance multi-family buildings were discussed, with focus on the operation of the collective ventilation systems with heat recovery, the indoor climate in the dwellings and user behaviour. The key monitoring parameters for a quick and automated detection of the main system failures were pointed out, with regard to the continuous commissioning and management of the buildings. Moreover the effect of the detected defects and failures on the energy performance of the dwellings was explored using dynamic simulations and monitoring data. It was found that important energy waste and indoor climate complaints can occur as a result of an inadequate operation of the building systems, even and especially when the total energy use of the systems is lower than expected. From this in-depth commissioning study it is concluded that commissioning of the building systems during occupancy is a vital part of the completion and operational lifetime of a residential building project, and a valuable contribution to its general performance assessment.

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