Learning from innovative climate concepts in schools

Stijn van der Horst [a], *Froukje* van Dijken [b]

[a] bba binnenmilieu, The Hague, the Netherlands, sh-bba@binnenmilieu.nl.

[b] bba binnenmilieu, The Hague, the Netherlands, fd-bba@binnenmilieu.nl.

Abstract. Newly designed buildings should be energy efficient as well as comfortable. To achieve both, new HVAC concepts are designed. Unfortunately, the introduction of new HVAC concepts is not always successful, leading to discomfort and even health complaints among the occupants.
In this paper we describe three cases that we investigated recently: 1) A school with concrete core heating/cooling and natural air supply and mechanical exhaust. 2) A school with an all-air system with VRF units and heat pumps. 3) A monumental school building (secondary school) with pressure regulated ventilation (BaOpt) and ground heat pump. The occupants had the following complaints in the three cases: 1) complains about cold air draught and cold feet in the winter, spring and autumn and heat in the summer season. 2) complaints about air draughts, fluctuating temperatures, bad air quality and unpleasant odours. 3) Complaints concern heat in summer, cold in winter and intermediate season, and stuffy and dry air. The causes found for the indoor climate problems for the three cases: 1) The combination of natural air supply and low temperature heating. A heating pipe was installed in front of the air inlet but was unable to prevent the draught. 2) The central AHU did not have heating or cooling sections. In defrosting mode of the air heat pump, fluctuating air inlet temperatures were measured. When defrosting, the ventilation system switched to recirculation, with implications for the IAQ. Different zoning of the ventilation system and the heating and cooling system exacerbated the problems. 3) Due to the low air tightness of the building envelope, the ventilation system did not perform as intended. Only the classrooms near the air handling unit got fresh air. The ground heat pump did not function due to underground leakages, therefor the school did hardly have heating and no cooling. From these cases we learn that it is crucial to bring together technical / theoretical knowledge, practical expertise and the user perspective when working on innovative solutions. In this way we learn from practical experience which hopefully lead to improved and robust HVAC-systems.

Keywords. HVAC concept, ventilation, concrete core activation, variable refrigerant flow, BaOpt, classroom
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1. Introduction

School buildings should promote learning performance and health and must be comfortable and energy-efficient as well. Current challenges include net zero energy buildings [1] and the Dutch energy transition as well as climate change. Besides the current pandemic asks for new ventilation regimes [2]. To achieve all these aims, new HVAC concepts are designed. Unfortunately, in practice we see that buildings with innovative climate concepts do not always perform as expected, which leads to complaints about the indoor climate. It is important that we learn from those cases.

The aim of this paper is to discuss and share lessons from practical experience that we learned from school buildings with failing innovative HVAC concepts, in order to avoid problems in future buildings. We believe that it is crucial to bring together technical / theoretical knowledge, practical expertise and the user perspective when working on innovative solutions.

2. Method

In this paper we describe three cases of school buildings that we investigated in the past years.

The schools discussed in this paper all have innovative climate concepts (Table 1).
Moreover, in all these buildings occupants have complaints about the indoor climate. The schools asked us to investigate the complaints of the occupants in relation to the indoor climate.

Tab. 1 – HVAC systems of the case studies.

	case 1	case 2	case 3
Heating	Ground heat pump	Air heat pump	Ground heat pump
Heating output	Concrete core	VRF system	Floor heating
Cooling	Ground heat pump	Air heat pump	Ground heat pump
Cooling output	Concrete core	VRF system	Floor cooling
Venti-lation	Natural air supply and mechanical exhaust	Mechanical ventilation system	BaOpt (mechanical ventilation)

For our indoor climate investigations, including the case studies in this paper, we use the Building-in-Use (BiU) approach [3]. This is a method of indoor climate research that has been specially developed to map complex indoor climate problems in an efficient way. Within this approach an inventory of user experiences and a thorough inspection of the building, work places and HVAC systems for risk factors for indoor climate problems are essential. An investigation takes the following steps:

1. *Questionnaire.* The complaints of the employees were collected through an online survey.
2. *Building/workplace survey*. During an on-site investigation, the relevant building and workplace factors are mapped out. For example, building physical characteristics, furnishing materials and use.
3. *Installation survey.* Based on random samples, it was investigated to what extent the climate installations are functioning properly. For example, the general operation, control settings and the hygienic condition of the AHU.
4. *Measurements.* Relevant parameters are measured in several rooms. For example, instantaneous measurements of the amount of fresh air supply/exhaust or long-term measurements of the room temperature, air inlet temperature and/or CO_2 concentration.
5. *Analysis of building documentation.* For example, design specificities or commissioning reports.

3. Results

The paragraph is structured as follows for each case. First, the climate system is briefly explained. Second, we summarized the main complaints from the online survey. Finally, we describe the causes found for the indoor climate problems at the building and installation survey in combination with the (long-term) measurements and documentation were linked to the complaints.

3.1 case 1: concrete core activation and natural air supply

This school building (elementary school) is built in 2009. It has a ground heat pump and is heated and cooled with a concrete core system. The ventilation system is natural air supply and mechanical exhaust ventilation (see figure 1). Fresh air enters the room through baffle chambers above the windows. In front of the ventilation registers, a heating pipe is installed to prevent draught. Moreover, the ventilation system is occupancy driven. An occupancy sensor in the classroom detects if the room is in use. When motion in the room is detected, a signal is sent to open the exhaust air damper for the classroom.

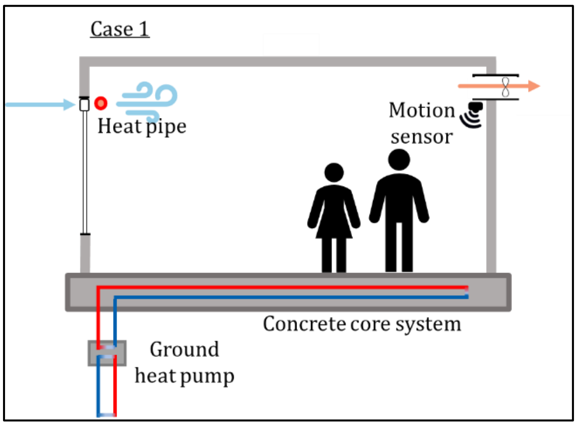

Fig. 1 – Case 1, schematic representation of climate concept.

In this school, the employees complain about cold air draught and cold feet in the winter, spring and autumn and heat in the summer season. Besides the employees have a sensation of dryness.

The combination of natural air supply and low-temperature heating causes complaints about draught in the winter period. The heating pipe in front of the registers seems not be sufficient to prevent draught.

The exhaust air damper can only be fully open or closed. When the sensor detects a person, the exhaust damper goes fully open which often doesn't correspond with the actual occupation of the classroom, for example in the morning and afternoon when only the teacher is in the classroom. This means that the amount of ventilation does not always fit the number of people in de classroom. As a result, too much cold air can be supplied into the classroom in the winter, which leads to complaints about cold and draught.

To prevent draught, employees close the ventilation registers above the windows in order to avoid the supply of cold outside air. As effect, the air from the corridor is sucked into the classroom instead of fresh air from outside, leading to a decreased air quality. Moreover, we found that closing both the registers above the windows and the door to the corridor this causes a fairly strong air stream over the floor through the gap below the door. This air stream contributes to the observed complaints about cold feet.

Because of the concrete core heating and cooling, open suspended ceilings are used. A disadvantage of the open suspended ceiling is that dust collects on top of it, which is detrimental to air quality. Contaminants irritate the mucous membranes, which is experienced as 'dry air' [4]. However, some classrooms suspended ceilings. In these rooms the capacity for heating and cooling was utterly insufficient, leading to thermal comfort complaints.

3.2 case 2: all-air climate system (VRF) with air heat pumps

The second school building (secondary school) is built in 2011. The building has an all-air system with Variable Refrigerant Flow (VRF) units and air heat pumps (see figure 2). The air handling units had recirculation damper but did not have heating or cooling sections.

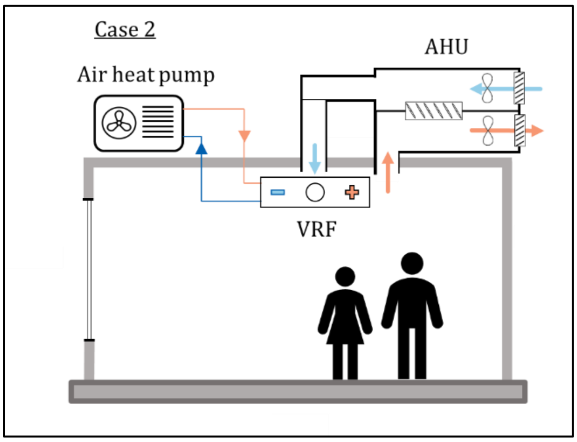

Fig. 2 – Case 2, schematic representation of climate concept.

The main complaints were about cold throughout the year, complaints about air draughts and complaints about fluctuating temperatures. In terms of air quality, there are complaints about 'dry', dusty, stale, stuffy air, and complaints about unpleasant odours.

A VRF system is less suitable for regulating a constant inlet temperature. In this case, the changes in the inlet temperature are larger, because the air handling unit does not preheat or cool the air. Besides this, in winter the air heat pump can turn into the defrosting mode. When the heat pump is defrosting, no heat is delivered to the VRF units in the classrooms. The result is that the inlet temperature can drop by as much as 30°C from 35°C to 5°C within 10 minutes (see figure 3), which, in certain outdoor circumstances, happened several times a day. Both the low inlet temperature and the changes in inlet temperature contribute to the complaints about cold, air draught, and fluctuating temperatures.

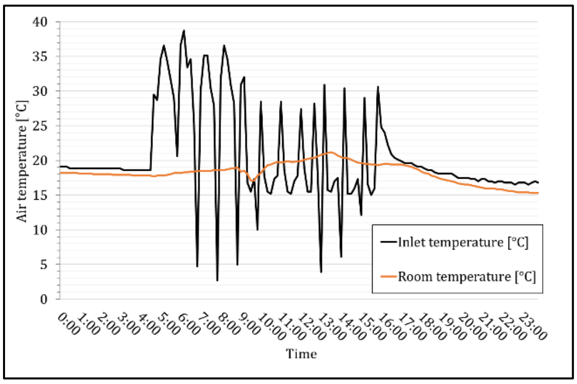

Fig. 3 – Measured inlet temperature and room temperature in a classroom of case 2.

To prevent cold air supply in the rooms when the heat pump is defrosting, the ventilation system can temporarily switch to the recirculation mode, which has a negative impact on indoor air quality in general. Since the exhaust of the toilets was connected to the central ventilation system, exhaust air from the toilets is spread through the building when the ventilation system is in recirculation mode. The odour of the toilets was noticeable in the classrooms, which explains the complaints about unpleasant odours.

Different zoning of the ventilation system and the heating and cooling system exacerbated the problems. The VRF units are divided into two zones: a south and a north zone. The ventilation system is divided into three zones: west, middle, and east. The disadvantage of this layout is that if one of the two air heat pumps must defrost, all air handling units will recirculate the air. As a result, air is recirculated more frequent than necessary during the heating season.

3.3 case 3: monument with pressure regulated ventilation (BaOpt)

The third school is a renovated monumental school building (secondary school). The building is renovated in 2015. The HVAC system is characterised by pressure regulated mechanical ventilation (BaOpt) [5] and a ground heat pump with floor heating and cooling (see figure 4). For the winter season, there are also gas-fired peak boilers.

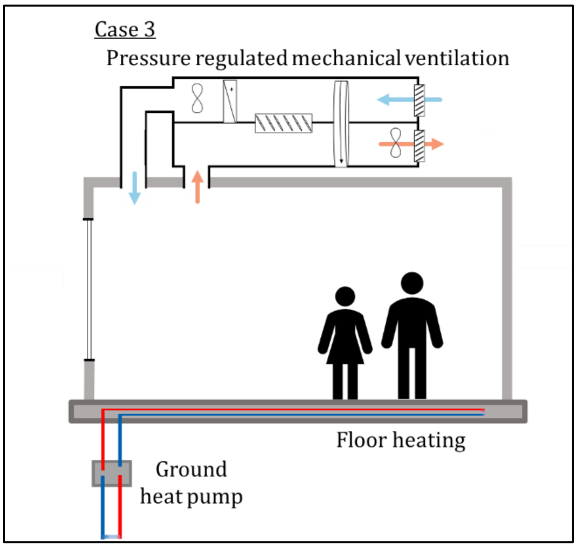

Fig. 4 – Case 3, schematic representation of climate concept.

In this building, the main complaints concern heat in summer, cold in winter and the intermediate season, and complaints about stuffy and dry air.

The complaints about air quality are caused by the fact that the pressure regulated ventilation system is not working properly. Due to the low airtightness of the monumental building envelope, the ventilation system did not perform as intended. The necessary pressure build-up hinders the proper functioning of the ventilation system. As a result, only the classrooms near the air handling unit got fresh air. All other classrooms were generally stale and warm and explain the complaints about stuffy air.

In addition, the air ducts seemed heavily polluted with dust and dirt that seemed to originate from the construction phase. This leads to complaints about 'dry air' (mucosal irritations) [4]. The air handling unit also has various components that are detrimental to air quality (including rotary heat exchanger, recirculation section) [6]. This enhances the complaints about stuffy air or 'dry air'.

To make things worse, the ground heat pump did not function due to an underground leakage. As a result, the school had hardly any heating and no cooling for few years. Because of non-technical issues the lack of heating and cooling capacity was only resolved a few years after the building was taken into occupation.

The lack of cooling and sufficient heating capacity explains the complaints about heat in summer and cold in winter. Because the heater battery also did not get any hot water, the supply air was not preheated. Also, the ventilation system was not working properly with as a consequence the heat recovery was not working. This explains the complaints about draught.

4. Discussion

Below, per case the problems related to the climate systems are discussed, indicating which lessons can be learned in the design of new school buildings.

Case 1 had natural air supply in combination with concrete core conditioning heating. To prevent air draught a heat pipe is installed in front of the registers. The results of the questionnaire shows that the heating pipe in front of the registers did not give the desired effect in preventing air draught. Because the registers can be open and closed by the occupants of the classrooms, the ventilation is not robust for occupant behaviour. From practice, we know that people will close those registers if they feel air draught from the registers, with as a result no fresh air is entering the classroom. Already in the design stage, this kind of problems should be thought out to prevent air draught and lack of ventilation in the classroom.

In a building with a concrete core system, the designer also needs to consider what kind of floor and ceiling can be used. The finishing should not affect the heating and cooling rate of the concrete core. In this case an open suspended ceiling was used. Disadvantage of open ceiling is that it catches a lot of dust. Some classrooms, though, had complete closed suspended ceilings. For those classrooms it seemed to have a serious impact on the cooling rates.

In case 2, several choices were made in the design stage with risks of a poor indoor climate. Fluctuating temperatures of the VRF system and the defrosting cycles of the air heat pump are well known characteristics of these systems. By not applying a heating battery in the air handling unit to cover thermal comfort issues, it is shown that too little attention has been paid to the comfort of the users during the design phase. The same applies to recirculating air in the school, knowing that the toilets are also connected to the same ventilation system. With a different zoning of the ventilation system and the heating and cooling system risks could have been limited.

Also, in case 3 the design stage was taken a risk using a pressure regulated ventilation system in combination with a monumental school building. One of the requirements for a good function this ventilation system is the airtightness of the building. In practice, we know that achieve an airtight building is difficult, especially for old buildings. We are not sure that the designers were aware of the importance of the air tightness of the building envelop with this kind of ventilation system. It seemed that no extra efforts were made to achieve the minimum airtightness needed. Note that opening windows, which is important for the perceived indoor climate in buildings, also affects the pressure differences in the building. Pressure regulated ventilation doesn’t work when windows are open.

The combination of an unsuitable ventilation system and the bad luck with the leakage of the ground heat pump made the indoor climate problems even worse.

Some of the complaints about the indoor climate in those three cases, could already be tackled in the design process of the buildings. Assessing the design regarding indoor environment/comfort is not yet a standard procedure in the design process. Also commissioning after completion of the building is not always common, in order to check if the climate system is preforming as designed. Evaluation of climate system in the design phase and a check of the building performance at completion and the first period of occupation by an independent indoor climate specialist seemed successful [7]. Therefore, we need clear and testable agreements about the performance. Finally, attention must also be paid to maintenance and operating costs in the design phase in order to make sure that adequate maintenance takes places in order to sustain the achieved performance.

5. Conclusion

The introduction of new HVAC concepts is not always successful, leading to discomfort and even health complaints among the occupants.

From these cases, we learn that it is crucial to bring together technical / theoretical knowledge as well as practical expertise and the user perspective when working on innovative solutions. In all cases studies already most of the problems which were found during the building investigation could be solved in the design stage of the building.

Moreover, it is important to monitor the performance and occupant satisfaction after introduction of innovative HVAC concepts. Only in this way we can learn from practical experience, leading to improved and robust HVAC-systems.

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Data Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.