The Cool Down Coach – An occupant oriented behavioural coach for effective ventilative cooling and solar shading

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Abstract
Due to climate change Dutch homes are increasingly suffering from overheating, which can lead to discomfort and sleeping problems that are detrimental for resident's health and wellbeing. Overheating can also lead to increased use of energy consuming air-conditioning devices. In mild oceanic climates overheating can largely be prevented through passive measures like solar shading and ventilative cooling. Previous research has shown, however, that residents do not always operate windows and shading devices effectively, sometimes opening windows at midday allowing warm air to enter or keeping windows closed at night preventing the home from cooling down with cool outside air.
This paper presents the results of a study aimed at the development and testing of a Cool Down Coach (CDC). The CDC is an internet-of-things enabled device that supports residents in keeping their home cool through effective use of ventilative cooling and solar shading. The CDC uses locally measured indoor and ambient temperatures, weather forecasts, and a user-interface, shown on a display and mobile phone. A prototype of the CDC was tested in seven homes in the Netherlands and from six of them, data and user feedback were obtained. Most residents reported that they found the CDC useful and accurate, making them more aware of their behaviour. The measurements provided useful insights to the tenants about their actual behaviour. However, monitoring showed that the advice from the CDC was not always followed. Reported reasons include fear of raining in and nuisance of insects (during daytime) and fear of burglary, nuisance of insects and outside noise (mostly during nighttime). It appeared that changing established behaviours remains a challenge, even with aid of the CDC. In conclusion, the CDC is a valuable tool for stimulating optimal cooling behaviour and providing insights, but it cannot, by itself, fully resolve overheating issues.

Keywords
Digital behavioural coach, advice, ventilative cooling, solar shading, indoor overheating

Introduction
Heatwaves and prolonged excess heat are increasing in frequency, duration, and magnitude due to climate change (World Health Organization 2024; KNMI 2015). Residents are increasingly suffering from indoor overheating, which can lead to discomfort and sleeping

problems that are detrimental for their health and wellbeing (Kenny et al. 2024). Indoor overheating also leads to increased use of energy consuming air-conditioning units. In mild oceanic climates, indoor overheating can be managed through passive measures like solar shading and ventilative cooling (van Hooff et al. 2014). Previous research has shown, however, that residents do not always operate windows and shading devices effectively (Schiela and Schünemann 2021; Schünemann, Schiela, and Ortlepp 2021). For example, they may open windows during the day (when it is hot outside) because a breeze feels cool, but this cooling effect is mainly due to evaporation on the skin. Or they may leave the windows closed at night, when the effect of ventilative cooling is much greater than during the day (i.e.: lower ambient temperatures at night). This may apply even more to well-insulated homes because they do not cool down quickly once they have heated up (van Hooff et al. 2014). In order to assist residents in when to open or close windows and when to operate solar shading, we developed a digital assistant called the Cooldown Coach (CDC).

Approach

We started by conducting interviews with potential future users of a CDC to understand their needs and preferences. Participants were recruited through the housing association Woonstad, in Rotterdam. Based on the interview findings, a prototype of the CDC was developed. The CDC uses sensors like indoor and ambient temperature and contact sensors that indicate if windows are opened or closed. The CDC was subsequently tested in a pilot consisting of the homes of seven tenants from housing associations Woonstad in Rotterdam and De Alliantie in Amsterdam. In order to evaluate the CDC, sensor data were collected and analysed. The analysis was enhanced with the results of exit interviews, where tenants were asked about their experience with the CDC and reasons for (not) complying with its advice.

Results interviews with residents about their needs and preferences

Tenants were recruited through the Woonstad Meedenkers (‘Think along’) panel. This panel consists of approx. 900 residents that can be consulted in relation to tenants’ issues. Woonstad inquired whether tenants in the panel would be interested in participating in the interviews. Residents were selected based on their experience with overheating, resulting in 13 tenants being interviewed in May 2024. The interviews, lasting one hour, took place at the main office of Woonstad. Topics included the tenants’ experiences with indoor overheating, measures they took to avoid it, and their needs of and preferences on mitigation measures. Tenants reported that they measured temperatures of over 30ºC in their bedroom or living room, even at moderate ambient temperatures. Most tenants attributed overheating to solar irradiation passing through the windows. They also indicated that they were aware of the importance of ventilating the home, but they also reported barriers to opening their windows at night for fear of burglary, outside noise or insects. None of the homes had any outdoor solar shading. When asked about measures they took to prevent overheating, tenants reported mounting improvised aluminium foil or a piece of cloth on the windows, using a fan and small air-conditioning units, mostly to little avail. Most tenants were keen to have an air-conditioning unit or outdoor solar shading, but according to tenants, the housing association could not or would not provide these and also did not allow tenants to install outdoor shading. Additionally, tenants did not want to invest in solar shading themselves for a property they do not own.

Tenants were also asked what they thought of the idea of a CDC. They were generally enthusiastic, but at the same time doubted whether it could solve all of their overheating problems. Researchers showed some examples of what the interface of the CDC could look like. The majority of the tenants preferred a simple layout with icons and colours to indicate the indoor temperature relative to the outdoor temperature to immediately know what action to take. All tenants expressed that having the display available on their phones would be a positive addition. Finally, tenants were also asked whether they would be interested in testing a prototype of the CDC.

Development of the CDC

Based on the interview findings, a prototype of the CDC was developed. The main elements of the CDC are the algorithm producing the advice and the interface.

Algorithm

The CDC's advice is produced by a relatively simple algorithm. More sophisticated features are available (see 'Future work') but these were not implemented in the pilot. The advice to open or close windows is based on the average of living room temperature and bedroom temperature and applies to all windows in the home.

The CDC advise is based on the logic described in Table 1. The CDC advises to open windows in order to cool the home when: (1) it is warm inside, i.e. when the indoor temperature exceeds a threshold that is determined using a fixed 'comfort temperature' of 21°C and a 1.5 ºC offset above this temperature, and (2) it is sufficiently cool outside (ambient temperature more than 1 ºC below the indoor temperature). The CDC also advises to open windows to heat up the home when 1) it is cool inside ($T_{in} \leq T_{comfort} - 1.5$ ºC) and 2) sufficiently warm outside ($T_{ambient} > T_{in} - 1$ ºC). In other cases, the CDC advises to close the windows.

Due to the cooling effect of a breeze on people's skin, people often find it difficult to determine the ambient temperature relative to the indoor temperature.

Table 1. Rules for opening or closing windows

			Effect of admitting outdoor air:		
			$T_{out} \leq T_{in} - 1$	Else:	$T_{out} \geq T_{in} + 1$
			Outdoor air cools	No effect	Outdoor air heats up
Indoor temperature	$T_{in} \leq (T_{comf} - 1.5)$	It is cold inside	Close window	Close window	Open window
	Else:	It is neutral	Close window	Close window	Close window
	$T_{in} \geq (T_{comf} - 1.5)$	It is warm inside	Open window	Close window	Close window

The CDC also advises residents on when to lower the solar blinds based on the measured indoor temperature and irradiation data from the nearest weather station. However, since none of the homes in the pilot had any solar shading, only the CDC's advice on opening or closing windows could be evaluated.

Interface

Based on the preferences expressed during the interviews, the display shows red colours when it is warmer outside than inside (Figure 1, left) and blue colours when it is colder (Figure 1, right). This way, the residents can see at a glance what action to take.

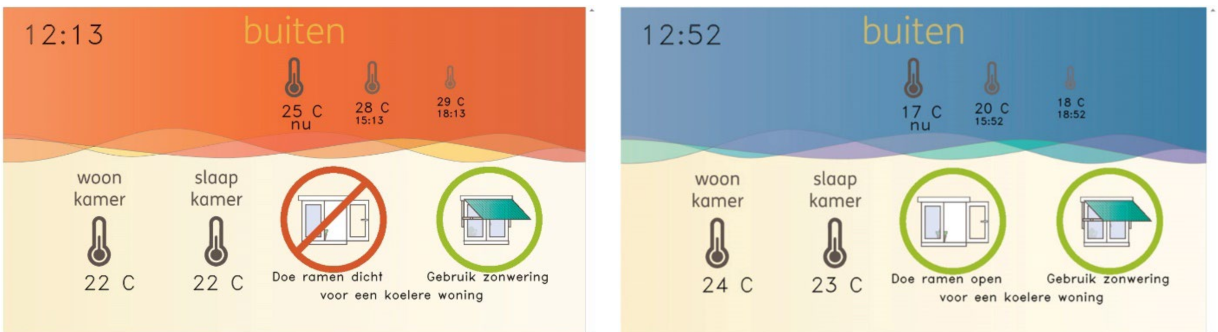

Figure 1 Display of the CDC in the situation of relative high ambient temperatures ('buiten') advising windows to be closed (left) and relative low ambient temperatures advising windows to be opened (right).

The display also shows the indoor temperature in the living room ('woonkamer') and the bedroom ('slaapkamer'), the current ambient temperature ('nu') and the forecasted ambient temperatures in 3 and 6 hours. Finally, it shows icons for opening or closing windows and lowering the solar shading.

Implementation of the CDC

In the pilot, the CDC consisted of the following elements:

- Three wireless temperature sensors to measure the ambient temperature and the temperature of the living room and a bedroom,
- Two wireless contact sensors indicating if windows were opened or closed in order to monitor the resident's behaviour,
- Predictions of ambient temperature and solar irradiation at the nearest weather station,
- A gateway collecting the sensor data,
- A modem connected to the internet through a 4G mobile phone network,
- An online server environment used to retrieve weather forecasts and running the algorithms used to generate the advice,
- A display, as shown in Figure 1. This display was also available as a personalized website on their phone.

The architecture of the CDC is schematically shown in Figure 2.

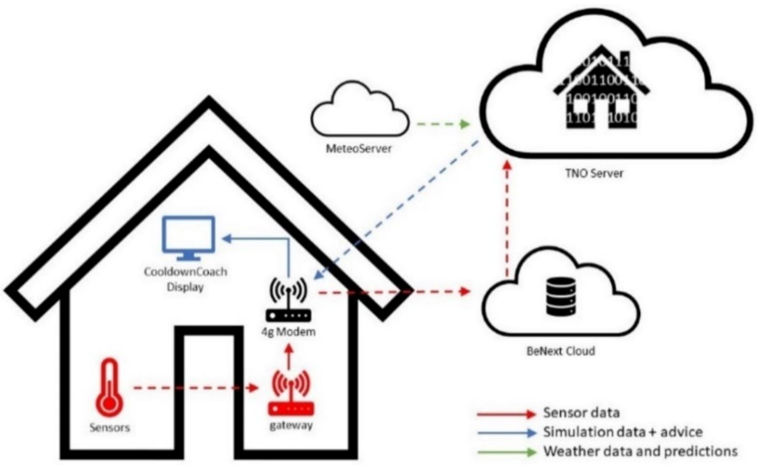

Figure 2 ICT architecture of the Cool Down Coach.

Pilot in seven homes

Three tenants from Woonstad in Rotterdam, who had previously participated in the interviews, volunteered to test the CDC. They were motivated by their interest in addressing overheating and contributing to the research. Two out of three tenants suffered from serious overheating problems, even outside of the period of actual heat waves. These homes included a one storey apartment built in 1997, a two storey maisonette apartment built in 1991, and a terraced house built in 1981.

In addition, housing association De Alliantie in Amsterdam expressed great interest in the project and was able to recruit four tenants living in the same multi-story apartment building built in 2020 in Amsterdam. These tenants had overheating issues and had ongoing discussions with the housing association on mitigation measures.

Two researchers visited each of the participants. One researcher would install the equipment and the other would explain the operation of the CDC. The pilot ran from May 27 till the end of August, 2024. During the first week of the pilot, some of the CDC screens malfunctioned, displaying a black screen or being flipped upside down. These issues were resolved within a day. The display on tenants' phones continued functioning throughout the pilot. Two tenants also reported inaccurate temperature readings due to sensors being placed near surfaces in direct sunlight or too closely to electric appliances, such as microwaves and refrigerators. The sensors were repositioned to correct this. Figure 3 shows two of the tenants’ homes.

Figure 3 Two example homes of the tenants, a single family home in Rotterdam (left), and an apartment in Amsterdam (right)

Analysis of the sensor data

The data from the sensors were analysed in order to assess the degree of overheating in these dwellings and the extent to which the occupants followed the CDC’s advice. To this end the actual window opening behaviour of the tenants was compared with the window opening suggested by the CDC. Because none of the homes in the pilot had any outer solar shading, only the CDC’s advice on opening or closing windows could be evaluated.

High ambient (and indoor) temperatures were recorded throughout various weeks in this period. Figure 4 shows the monitored temperatures and window opening behaviours from the living rooms of two homes during a warm six-day period from June 22 – 28, 2024. The graphs show the locally measured ambient temperature (blue line), indoor temperature (yellow line), the status of the window (green line where 0.9 is open and 0.1 is closed) and the window opening advice given by the CDC (green dot at 0.95 whenever the advice is to open the window).

The ambient temperature in the graphs show a number of sharp peaks that are most likely due to solar irradiation of the sensor or nearby surfaces. Particularly for house 3, a fully shaded outside location for the sensor could not be found around the house.

The top graph (house 3) shows residents that did not really follow the advice of the CDC, especially at night. The residents frequently opened the window at moments when the ambient temperature is higher than the indoor temperature (indicated by the red circles), causing the indoor temperature to rise. In addition, these residents mostly kept the windows closed at night when cooler outside air could have been used to cool the house.

The bottom graph (house 4) shows a dwelling where residents showed more effective ventilation behaviour. These residents did open windows at moments when the outside air was cooler than indoors (red circles) and kept windows opened throughout the night. Particularly during the three hottest days, the behaviour of these residents was consistent with

CDC's advice. These type of graphs were produced for each home and the insights from them were discussed with the tenants during the exit interviews (see below).

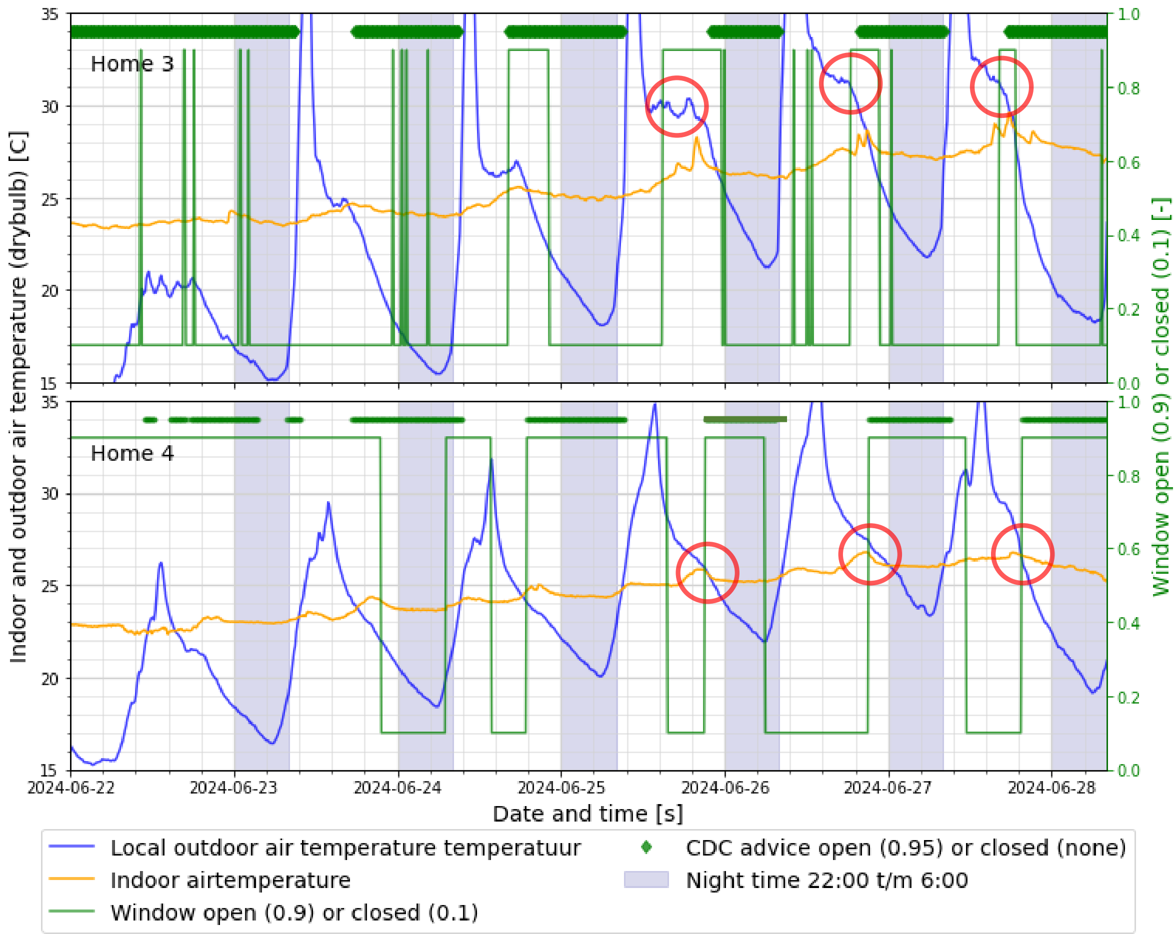

Figure 4 Monitoring data shown for a week with hot weather. Data from the living rooms of house 3 (top) and house 4 (bottom). The shaded areas indicate hours during nighttime (from 22:00 to 6:00).

Table 2 below shows temperature statistics for all homes. The table shows the part of the time that the indoor temperature exceeded 27°C (Tin27exc.) inside each home for both the living rooms (L) and the bedrooms (B) throughout the entire measurement campaign. The table shows there are substantial differences in the degree of overheating. Homes 3 and 6 were subjected to severe overheating (47-69% Tin27exc.), homes 1 and 5 showed some overheating (2-11%) and homes 2, 4 and 7 showed very little overheating (0-1%). Note that the resident in home 6 was not at home for long periods.

Table 2 Overheating in each house in terms of the share of time that an indoor temperature of 27°C is exceeded

	Home 1		**Home 2**		**Home 3**		**Home 4**		**Home 5**		**Home 6***		**Home 7****	
	L	B	L	B	L	B	L	B	L	B	L	B	L	B
A. Tin (27°C) exc.	11%	6%	0%	0%	47%	59%	0%	0%	4%	2%	54%	69%	1%	0%

* Resident was not at home for long periods, ** Resident reported occasional faults of sensor readings

Table 3 below gives insight into the degree to which residents followed the CDC advice. The table shows the part of time that the position of the windows (open/closed) agreed with the advice of the CDC throughout the entire measurement campaign. This degree of correspondence between the advice and the actual behaviour is computed using the 'accuracy'

statistical indicator (Fawcett 2006). It is the percentage of time that the windows are opened when the CDC advices them to be opened plus the percentage of time that the windows are closed when the CDC advices them to be closed.
Row D shows the accuracy for the living room windows of each house and shows that the behaviour in Home 2, 4 and 7 corresponded most with the CDC's advice. Home 6 showed the lowest accuracy (16%). However, since its resident was absent throughout most of the pilot, the accuracy shown is not representative of that tenants' response to the CDC.
Row E shows the same indicator but the window opening behaviour and the CDC advice are only compared at moments when either one of the indoor temperatures or the ambient temperature exceeds 25°C. For all homes, the accuracy is higher than in row D. This suggest that tenants were more inclined to follow the CDC's advice when it was warm. Row F and row G of the table show the accuracy for daytime only (7:00-22:00) and nighttime only (22:00-7:00) periods respectively. For all living rooms except that of home 7 the accuracy is higher during the day than at night. Further analyses showed that this is because the residents closed living room windows during the night, even when cool outside air could have been used to cool the home.

Table 3 Agreement between the actual window opening/closing behaviour and the advice of the CDC.

	Home 1	Home 2	Home 3	Home 4	Home 5	Home 6	Home 7
Living room						*	
D. Accuracy all [L]	43%	64%	30%	72%	18%	~~16%~~	53%
E. Accuracy hot [L]	54%	88%	33%	78%	21%	~~18%~~	73%
F. Accuracy day [L]	50%	76%	42%	68%	24%	~~27%~~	53%
G. Accuracy night [L]	34%	45%	10%	78%	4%	~~1%~~	53%
Bedroom							
H. Accuracy all [B]	29%	49%	94%	76%	97%	~~85%~~	81%
I. Accuracy hot [B]	34%	49%	93%	82%	96%	~~83%~~	77%
J. Accuracy day [B]	36%	50%	90%	72%	95%	~~74%~~	73%
K. Accuracy night [B]	18%	48%	99%	83%	100%	~~100%~~	93%

* Respondent of home 6 was not home for long periods

Rows H to K show the same accuracy scores for the bedroom window. Overall, accuracy values were higher than in the living rooms. Here, accuracy did not increase with higher temperatures for every home. Additionally, accuracy is higher when considering nighttime periods compared to daytime periods. Measurements showed that that most residents often opened bedroom windows for prolonged periods, regardless of indoor or ambient temperature. This agrees with findings in other studies that resident in the Netherlands often open windows (possibly ajar) in bedrooms during the night (Koene, 2021). Since the CDC often advises to open windows at night for effective cooling, this results in high nighttime accuracy values.

Evaluation of the CDC from user feedback

The sensor data was combined with the results of exit interviews with the tenants, evaluating their experience with the CDC. Tenants were also asked about their degree of compliance with the CDC advice, based on the analysis of the sensor data. All three tenants of Woonstad as well as three out of four tenants from De Alliantie in Amsterdam were interviewed after the

pilot[1]. As participants from the two associations were motivated by different issues, results and experiences from both groups varied accordingly.
In general, the tenants of the housing association Woonstad were rather content with the CDC, in fact all three tenants gave the CDC a score of 8 out of 10. They found the advice of the CDC to be clearly displayed and easy to understand. They specifically reported that the dark colours of the equipment made the CDC fit aesthetically well in their home. These tenants mentioned that using the CDC became part of their routine, and that they looked at the displays multiple times a day. In the beginning, two out of three tenants would check the advice of the CDC and then proceed to open or close windows. After a few weeks however, the pattern was reversed: tenants would first open or close the windows, and then check for confirmation by CDC. They started to use the CDC as an instrument to 'validate' whether their behaviour was effective. This indicates that the CDC made the tenants more aware of their ventilating behaviour. One tenant also mentioned that her routines changed, and that she opened her living room window more than she used to do during previous summers.
The tenants of housing association De Alliantie on the other hand were less content. They mentioned that for them the main added value of the CDC was being able to monitor indoor temperatures to see if their complaints of overheating could be substantiated. Two of the tenants reported to be already aware of their behaviour and that the CDC merely served to confirm their (apparently) correct behaviour. After that, they did not use the CDC that often anymore.
Tenants from both groups noted the CDC occasionally displaying temperatures that were off by 5 ⁰C intuitively, or compared to other weather apps and thermostat indicators. The reasons for these discrepancies were not always clear. Most issues were resolved with updates, but in one case, this led a tenant discontinuing to use the CDC.
When asked about reasons for non-complying with the CDC's advice, tenants mentioned several factors: allergies to insects, rain, being away on holiday or work, concerns about the building's susceptibility to burglary and outside noise, and children sleeping in separate bedrooms, which made it difficult for parents to ensure adherence to the CDC's advice. Additionally, one tenant noted that even when it was warmer outside than inside, opening the window provided a cooling breeze and much-needed ventilation, which is why the tenant chose not to follow the CDC's recommendations.
When asked about the effectiveness of the CDC, the reactions were mixed. Two tenants mentioned that opening the window at night indeed cooled down the rooms where they or their children were sleeping. Other tenants thought that opening windows did not have much effect. Especially during the day and in particular on very hot days, tenants mentioned that they were unable to cool their home, even when they followed the advice of the CDC. All tenants therefore believe that more structural interventions are necessary to prevent overheating, mostly mentioning outdoor solar shading. One tenant mentioned that although she opened the window and doors when it was cooler outside than inside, it took a long time for the bedroom to cool down. Another tenant mentioned that although she purchased an exterior solar shading device with suction cups, she would prefer permanent outer solar blinds and wanted the housing association to take such measures. One tenant from Woonstad wished that the housing association would install window screens against insects and other animals.

Suggested improvements of the CDC

[1] The tenant from home 6could not be contacted at the time of writing and was mostly away from home during the pilot.

All the tenants of housing association Woonstad mentioned that they would like to keep using the CDC or similar technologies. However, they did mention several suggestions to improve the CDC. The first suggestion is to build in the option to set a ‘desired air temperature’ or ‘comfort temperature’, so that the CDC adapts its advice accordingly. The second suggestion is to incorporate more building characteristics into the CDC, such as the window size and thermal insulation of the walls. The reasoning behind this it that the CDC can take these characteristics into account to advise future users more accurately.
All tenants of De Alliantie mentioned that they would *not* use the CDC or similar technologies again because they thought they already operated windows effectively for ventilative cooling, so to them the CDC was of little added value. They did see potential for the CDC to automatically control the outdoor solar blinds, if they were to be installed, which is a feature they strongly wished for and that they expected their housing association to install. In a future version, they would appreciate being able to adjust the brightness of the screen, as they found the display of the current CDC prototype too bright.

Future developments
Several future features could enhance the CDC’s functionality and adaptability. In the current version all CDC’s use a fixed ‘comfort temperature’ (e.g. 22ºC) that determines a threshold for windows to be opened or closed. As suggested by some of the tenants, a more advanced version could allow individual setting of this 'comfort temperature’. In addition, the desired comfort ranges could be varied in relation to the outside temperature following findings from adaptive comfort literature. Another useful feature may be to use logged measurements in conversations and disputes between tenants and housing associations. In the Netherlands, a reduction in rent can be applied for by tenants if there are more than 300 hours per year where indoor temperatures exceed 26.5 °C. Temperatures logged by the CDC could be used to calculate these temperature exceedance hours and potentially shown on the display.
Data from the CDC could also be used to support decision making on building related measures. A thermal building model could be calibrated using logged data and used for scenario analyses, such as evaluating and displaying the effects of implementing exterior solar shading, solar control glazing or ventilation hatches.
The logic behind the advice of the CDC could be improved by including advice aimed at pre-cooling the home in the morning if a warm afternoon is forecasted. This would involve an advice to open windows even if the indoor temperature is below the comfort threshold if a warm day is forecasted.
Furthermore, integrating a pollen forecast in the advice could be beneficial, advising users to close windows during high pollen concentrations. In addition, a dedicated mobile app could be made instead displaying a web page on mobile devices as in the current version. Providing a helpdesk or support service when the coach malfunctions could increase acceptance by the users. Finally, the CDC may be applied to other types of buildings than homes, such as schools, shops, or utility buildings to help with optimal cooling behaviours.

Limitations
The study had several limitations. It was conducted within a short timeframe, utilizing limited resources. The initial interview involved 13 participants and the pilot involved only six motivated tenants, which are numbers that are not representative of the general population in terms of knowledge on ventilate cooling behaviour and motivation to change their behaviour. The participants in this study were already knowledgeable about preventing overheating. Finally, the CDC was still in its prototype version, so some issues could not be fully resolved, leading to suboptimal performance in the pilot.

Conclusions

The Cooldown coach (CDC) appeared to be a welcome tool overall, reducing indoor temperatures by supporting optimal use of ventilative cooling. The CDC made residents more aware of their behaviour with respect to ventilative cooling. Some residents reported less overheating, but for those already showing effective behaviour, the impact was less. In these cases, the CDC confirmed their overheating issues and served to substantiate their claims to the housing association.

However, the results of this study show that in practice residents do not always follow the CDC's advice, resulting in sub-optimal ventilative cooling behaviour. Reported reasons for this include fear of rain coming in through the window and nuisance of insects (during daytime) and fear of burglary, nuisance of insects and outside noise (mostly during nighttime). Measures for addressing the latter are recommended (e.g.: sound- and burglary proof ventilation hatches and insect screens), as nighttime ventilative cooling has a larger effect on cooling than daytime ventilation.

From this study, we can conclude that the CDC is a valuable tool, but it cannot, by itself, fully resolve overheating issues. Especially in solar-exposed façades with large windows, more structural measures need to be taken, like exterior solar shading.

Acknowledgements

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