# How to transform European housing into healthy and sustainable living spaces using a Belgian case study? – the RenovActive principles tackle climate and renovation challenges

Petrus te BRAAK[2], Joeri MINNEN[2], Moritz FEDKENHEUER[3]; Bernd WEGENER[3], Friedl DECOCK[4], Filip DESCAMPS[4], Sabine PAUQUAY[5], Lone FEIFER[1], Lara Anne HALE[1], Thorbjørn Færing ASMUSSEN[1] and Jens CHRISTOFFERSEN[*1]

[1] VELUX A/S, Hoersholm, Denmark
[2] Vrije Universiteit Brussel, Brussel, Belgium
[3] Humboldt University, Berlin, Germany
[4] Daidalos Peutz, Leuven, Belgium
[5] VELUX Belgium, Bierges, Belgium
** Corresponding author: jens.christoffersen@velux.com*

**ABSTRACT**

The RenovActive renovation concept seeks to offer healthy, affordable, easy to reproduce, scalable solutions for the existing building stock of European housing. The concept was developed and tested in a prototype phase, where 7 principles have been applied to a semidetached house built in the 1920s, situated in a garden city in Brussels. The renovated prototype was occupied by a family and monitored for two years. The monitoring was performed, after renovation, both through data, sensors, and extensive interviews and questionnaires with the family. In general, the family living in the house is very satisfied with the indoor environment. The results show a general indoor $CO_2$-concentration below 900 ppm, and an indoor temperature between 21°C and 26°C. The technical and sociological monitoring show indication for the additional potential to optimize and improve indoor comfort levels and perception. As an example, there are discrepancies between setpoints and programming we initiated, based on standards and scientific inputs, based on predicted behaviors. But user interactions, and preferences in real life situation when occupying the house, as well as situational perceptions and culture, modified user setpoints compared to our initial setpoints, that in some settings could have a negative impact on the indoor environment. This indicates that a technical system operating the indoor environment must be both flexible and robust to accommodate for multiple and varying preferences of building inhabitants.

## INTRODUCTION

From 2008-2012, several Model Home 2020 demonstration buildings were designed and constructed (Foldbjerg et al, 2015). The objective of the Model Home 2020 project was to combine an excellent indoor environment with high energy efficiency. Thereby, the houses were designed, built, and constructed as state-of-the-art homes with the newest technological developments and high-quality materials, and designed to strike the best balance between the three Active House principles (Active House) (Figure 1):

- Comfort: the building should provide indoor living conditions that support the health and comfort of its inhabitants
- Energy: the building achieves high levels of energy efficiency and makes use of renewable energy
- Environment: the building has a minimal impact on the environment.

In the Model Home 2020 projects, all buildings were monitored in use to measure and understand both the buildings' performance and the perception of the occupants. From the monitoring part, one of the conclusions was that it is possible with available products and technology to meet the 2020 energy requirements without compromising sustainable living.


*Figure 1 - The Active House principles*

The need for meeting legislative requirements is especially poignant with pre-existing structures. The RenovActive project builds on these learnings while focusing on the renovation. Indeed, all the current dwellings in Europe have been built between 1945 and 1980, and the average age of our total building stock continues to grow increasingly older. Eurostat has registered a 30% decline in construction output in the EU's 28 member states since 2008. If the trend continues, 90% of our current residential properties will still be in use by the year 2050. The RenovActive project in Anderlecht seeks to offer healthy, affordable, scalable solutions (VELUX, 2016) by testing the Active House principles in social housing and the single-family housing segment. The house was abandoned prior to renovation.

## SEVEN PRINCIPLES FOR A HEALTHY AND AFFORDABLE CLIMATE RENOVATION

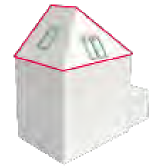
A key aspect of the RenovActive (Figure 2) project is to prove the financial viability of a renovation according to the Active House principles (see AH web site) in social housing across Europe, where challenges are:

- Ill-maintained homes are more common in rental properties due to tenants' lack of ownership
- Energy poverty means that nearly 11% cannot afford to heat their home sufficiently
- Unsuitable behaviors, e.g. lack of regular airing and the drying of clothes indoors, lead to a bad indoor climate

*Figure 2 RenovActive prototype before and after renovation*

Dividing the concept into seven individual building elements makes it possible to create a better match between the financial plan of the project and the different needs of the housing company, and the very wide span of existing housing conditions. To be able to meet the different points of departure, and enable a standardized approach, the affordability concept bases on the proven quality of each principle, as well as the ability to be reproduced, allowing economies of scale to take effect; as such it is an approach of systemic enablement with a combination of elements.

*Table 1: Seven principles applicable and cost-effective solutions for renovation. All principle was applied.*

| | |
|---|---|
| 1: Attic conversion: The attic is converted into living space (area 12,5m2) and connected to the home via an open stairwell. |  |
| 2: Increased glazed area: Distribution of windows (both new and existing) in every room and on every floor to improve daylight conditions |  |
| 3: Staircase shaft for daylight & ventilation: An open stairwell topped with roof windows allows ventilative cooling through open roof windows as well as downward daylight distribution. |  |
| 4: Dynamic sunscreening: External sun screening reduces overheating. |  |
| 5: Hybrid ventilation system: During summer, windows and stairwell are used to provide natural cooling in the building, During winter, mechanical ventilation maintains indoor air quality and while limiting the risk of draughts. |  |
| 6: Improved thermal envelope: New facade insulation, new roof construction, and new windows all around ensure reduced energy consumption. New ground floor heating and modern radiators on the 1st and 2nd floors. |  |
| 7: Building extension: The extension (area 15m$^2$) creates additional living space on the ground floor and space for one more family member in total. |  |

The RenovActive Concept is based on seven principles, seen to be the most applicable and cost-effective solutions for renovation (Table 1). Each element is created to give existing buildings the ability to perform on the same level, or close to, as newly built houses. Depending on the existing building design and renovation budget, the different elements can be implemented to increase the level of daylight, improve ventilation, strengthen the envelope or expand the living space through densification or extension. The concept's modularity adapts to each house typology.

To investigate the concept, the house has been tested by the first family to move in and monitored post-occupancy to evaluate how the elements function in practice. The post-occupancy evaluation is conducted by a research team of social scientists and engineers. The sociologists took a close look at the occupants' perspective, experiences, and interaction with the building. The engineers checked the physical data and performances of the house. The post-occupancy monitoring of the first RenovActive project wanted to explore the performance of this healthy and affordable renovation, targeting both energy savings and user comfort.

The following targets were laid down to make the RenovActive House in Belgium a success and validate the concept - all of them were met by the completion of the project:

- Indoor climate: The house offers high daylight levels, protection against overheating, and a good indoor air quality
- Affordability: The renovation (incl. all technical equipment) is executed within the budget lines of social housing in Brussels
- Reproducibility: The concept should be based on existing technologies and materials
- Energy performance: The primary energy use complies with the strict Brussels EPB (Energy Performance of Buildings) legislation

**From an occupant perspective**

The sociological monitoring included three different instruments of data collection and several data collection points (te Braak et al 2020). There were face-to-face-interviews, online questionnaires and a time-diary-tool. These three instruments were linked together, and each is referring to the other. After filling in questionnaires, the adults were interviewed face-to-face by a scientist, directly after the interview, both adults were asked to fill in a time diary for a one-week period. The online questionnaire quantified the opinions, level of satisfaction and comfort behaviour of the dwellers, an input that was then extended during the face-to-face-interview. The interviews served furthermore the purpose of clarification of various points, like comfort behaviour and the actual experiences of specific comfort related situations. The online time diary gave us a detailed view on how the house is used and where the family spends most of the time. Each activity that was registered was followed up by a supplementary short questionnaire. This questionnaire asked how the comfort is perceived during the activity, what they did in order to further improve their comfort during the activity, where they were during the activity and with whom. Sleeping activity was followed by a more specific questionnaire, asking the family how they rate their sleeping quality. The qualitative data were collected: before (in the family's former home) – questionnaire and interview; after moving in, we collected questionnaire, interview and time diary Autumn 2017, Winter 2018, Summer 2018, Autumn 2018, Winter 2019, and Spring 2019.

**From a monitoring perspective**

The post occupancy building monitoring included measurements of indoor air quality and thermal comfort, as well as energy consumption. The monitoring aimed at establishing knowledge and documentation on the house's performance, the inhabitants' perceptions and on the contribution of the different renovation principles to both. We included additional measurement boxes (by a raspberry pi) and logged temperature, relative humidity, CO2, light and opening distance of the door. These measurements started July 2017 and ended September 2019. In addition, we added a Netatmo weather station to measure the outdoor climate (outdoor temperature and relative humidity), as well as indoor modules measuring temperature, relative humidity, noise and CO2. We use the weather data available for Ukkel (close to Brussels) from National Oceanic and Atmospheric Administration. The monitoring of the energy consumption is partly building related and mainly plug load. The monitoring of the energy consumption occurs by Emonpi en EmonTx. It was not possible to monitor the gas and water consumption due to the kind of utility meters, but the electricity consumption was reported.

**Methodological challenges**

In this project, there proved to be several methodological challenges to be dealt with when monitoring and evaluating the results, the most prominent one being the dependency on a single case exploration, which makes generalizing difficult Some findings can thus be to some extent, related to the observed family and the special conditions of their former home.

## RESULTS

The before interview to place just prior to the family moved to RenovActive. We have tried to take into account that the family's former home was in a really bad condition. In the before interview the family complained about several significant building deficits, they experienced in the old house, for instance bad insulation, insufficient heating, dampness and poor noise insulation. Therefore, the level of comfort increased substantial when they moved into the RenovActive building, leaving limited space for critical assessments of the house or its parameters. However, supplementing the questionnaire with interviews, we were able to have a more 'modifed' perception of their new home. The complete questionnaire is available in te Braak et al (2020).

The complete monitoring program took place from July 2017 until September 2019. Data from the social monitoring (te Braak et al 2020, Vrije Universiteit Brussel, 2019) show that the family is very satisfied with the level of indoor comfort. In the questionnaires, the time diary as well as during the interviews, the family stated that they were very happy with the indoor temperature, the indoor air quality, and daylight levels. However, the family pointed towards too high temperatures during the summer months of the first year. Based on this feedback, adjustments were made to the ventilation system to improve the stack effect of the staircase by automatic window openings. Moreover, a better solar shading device in the attic significantly improved indoor comfort. The occupants perceived the house to be well-lit by daylight thanks to the different windows, even if they were using the ground-floor solar protection almost all the time for privacy reasons. There is generally enough space for the family and the layout ensures that the house can be used optimally.

To further improve the level of comfort, the family had various options to adjust appliances manually, such as opening windows, lowering blinds, adjusting heating and ventilation systems, etc. Besides daily adjustment of the heating in the bedrooms during winter, and the opening of windows during cooking and cleaning in order to let the 'smelly' air out, few adjustments were made to improve the indoor climate. Nevertheless, occupants reported a sense of being able to adjust the different indoor parameters according to their needs, and when doing so, to experience an improvement of the indoor environment. Interestingly, the ventilation system as well as the home automation system was left unadjusted, along with sporadic manual window opening to cool down the house.

The mother reports positive development in her state of health. She reported irritated airways in the former home because of high humidity during winter. This has disappeared. The quality of sleep has also been greatly improved since the family moved in. Although the general perception of the house is very positive and associated with an increase of happiness, health level, and overall wellbeing, there are a few elements that occupants identify as challenging: the presence of mosquitos during the night, lack of outdoor storage facilities, and a technical mistake of the slope of the bathroom floor.

Apart from the common criticism of the case study method, it's dependency on a single case exploration making it difficult to reach a generalising conclusion, there are several methodological challenges that had to be dealt with when monitoring and evaluating the RenovActive project. These challenges are mainly related to the observed family and the special conditions of their former home:

1) There are slight discrepancies between the results from the online instruments and the personal interviews. While the family does give critical statements through the impersonal instruments, they refuse to verify these results in a personal interview. When asked, they answer according to the same pattern: "Oh that must have been a mistake". There are two possible explanations to this; the questionnaires and time diaries are not always filled in well (critical answers happen accidentally) OR the family feels uncomfortable criticising the RenovActive project in a personal face-to-face situation with a researcher. We decided to tackle this challenge with two strategies: We emphasised the importance of accurate and conscientious data collection and we told the family before each interview, that honest and critical answers are not offensive to anyone but important for the success and improvement of the project.'
2) The before situation of the family's old home was very poor. This means that the family, when evaluating the RenovActive house, frequently refer to a former situation that is neither comparable to their actual situation, nor to a situation of that is representative for other families. The positive reactions need to be put into this perspective. Coming from a small, cold and damp place, even an average indoor climate condition feels like a huge upgrade. This critical before situation hampers the design of the study and is the biggest methodological challenge.

From a monitoring perspective (daidalos peutz, 2019), the results show that the indoor air quality is very good. The hygienic ventilation system, Healthbox, in the house is a demand-controlled ventilation system with natural supply vents and mechanical extraction, designed according to Belgian standards. The hygienic ventilation system uses $CO_2$ setpoint of 850 ppm, while natural peak ventilation automatically control the façade windows when $T_{outdoor} > 15°C$; $CO_2$ setpoint of 1100 ppm or $T_{outdoor} < 15°C$; $CO_2$ setpoint of 1500 ppm. When the natural peak ventilation performs well, the CO2-concentration should be mainly lower than 1600 ppm.

Figure 3 shows the schematic diagram, where the control is based on the indoor and outdoor temperature. When the outdoor temperature is above "minimum outdoor cooling temperature", the mechanical ventilation is reduced to the lowest possible airflow (an airflow has to be maintained as the Healthbox unit contains the indoor climate sensors). In this situation, an automatic opening of the windows is used to control the indoor climate. Below the setpoint, the mechanical ventilation runs in demand control mode with the manual opening of windows as a backup system.

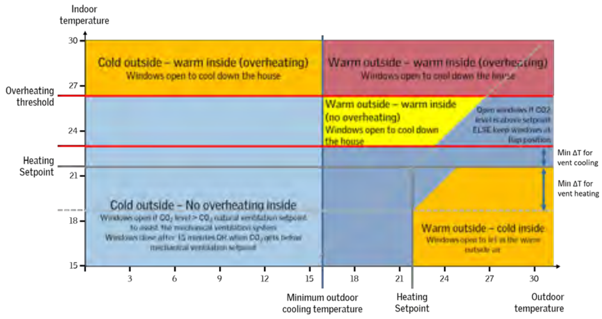



*Figure 3: Schematic diagram explaining the hybrid ventilation system of the Healthbox.*

The mechanical extract ventilation was roughly 9 L/s for the bedrooms, independent of the number of occupants, and 22 L/s for the kitchen. Additionally, peak ventilation through automatically controlled window openings is available. The control of the switch between hygienic and peak ventilation is based on indoor air quality parameters ($CO_2$, RH) and indoor air temperature. The setpoint for the mechanical extract ventilation is 850 ppm. During warm periods, windows open at 1100 ppm and during winter at 1500 ppm (natural peak ventilation is thus used as a backup for the mechanical system providing hygienic ventilation). The design goal was to maintain at least category II of EN 16978-1 (European Committee for Standardization, 2019), Table B.12, corresponding to 1200 ppm (outdoor level 400 ppm).

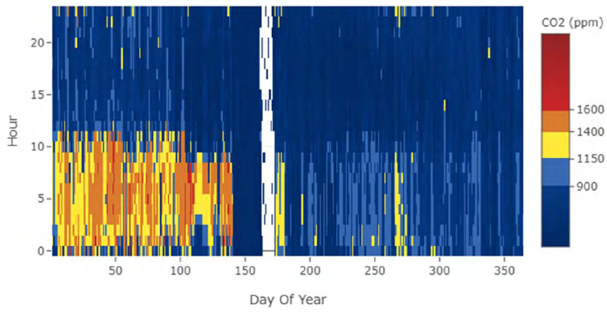



*Figure 4: Temporal map of the $CO_2$ concentration in the parent's bedroom, 2018. Each column represents one day of the year and each of the rows the hours. The color scale indicates the $CO_2$ level. The white area around May is due to a period of missing data.*

For more than 95% of the time, the $CO_2$-concentration in the house, in general, is below 900 ppm. Slightly higher $CO_2$ values were measured in the parents sleeping rooms (e.g. 1100 ppm, Figure 4). The higher values in the beginning of 2018, is mainly due to natural peak ventilation with higher CO2-setpoints. In addition, the mechanical ventilation system did not perform according to the intended strategy from the beginning, due to some of the supply vents were unintentionally closed. Also, the fan system was set, by the family, to eco-mode instead of demand control mode due to noise, resulting in low ventilation rates. After some adjustments, and instructions to the family, the $CO_2$ concentrations is maintained around 800 ppm by the ventilation system. Some issues with mosquito protection and safety, caused the automatic operation of the staircase windows and attic window to be turned off at night.

The kitchen is in open connection with the dining and living room. The inhabitants open the windows while cooking, instead of using the kitchen hood. Overall, the relative humidity is between 45-60% most of the time, and never below 30%, with the exception of the kitchen and bathroom, In the kitchen, the relative humidity is above 60% for about 15% of the measured hours.

Indoor temperature measurements show that the thermal comfort is good, but in the case of extremely hot temperatures, indoor temperatures increase quickly if the solar shading devices are not used as intended. The temperatures in the living and dining room (ground floor) stay for more than 95% of the time between 21°C and 26°C (e.g. similar to category II of EN 16798-1 Table B.4), with limited temperature below 20°C (Cat III) and temperature above 27°C (Cat III). The temperature in the bathroom are most of the time 'too low' (Cat V), while the attic has slightly higher values, but stays under 28°C, after improved staircase- and attic-window openings, especially by encouraging the family to use cross ventilation in the attic to reduce peak temperatures. During the 2018 hot spell, the indoor temperatures were too high, and the automatic system did not resolve this but could have been improved by ensuring cross-ventilation operation. Table 1 gives an overview of the mean temperature in the house during winter 1 (October 2017 until April 2018) and winter 2 (October 2018 until April 2019).

*Table 1. Mean winter temperature °C in the house.*

| Room | Winter 1 | Winter 2 |
|---|---|---|
| Living room | 22,1 | 21,8 |
| First floor | 20,9 | 20,1 |
| Attic | 19,8 | 12,2 |
| Outdoor | 7,2 | 7,0 |

In the design process, measures were taken to realize a good thermal comfort in the house. In 2018, the thermal summer comfort in the house was not good, but summer was a very hot and automated control system of the natural peak ventilation could only be controlled manually and the family barely open the windows or use the solar shading actively to improve the comfort. After the automated solar shading system operate according to intentions, the thermal comfort was improved. In addition, an automatic opening of the roof windows in the staircase continued to improve the both cross and stack ventilation, Table 2 show the mean summer temperature in the house.

*Table 2. Mean summer temperature °C in the house. T1 is before the family moved in, while the other three time periods are with different options to improve summer cmfort*

| Room | T1, no occupancy, no screens, no window opening, no ventilation system | T3, no screens, manual window opening, ventilation system | T4, automated screens, manual window opening, ventilation system | T5, automated screens, manual window opening, ventilation system, new control Velux Active attic - staircase |
|---|---|---|---|---|
| Living room | 24,9 | 24,7 | 25,3 | 24,1 |
| First floor | 27,3 | 27,6 | 27,6 | 26,3 |
| Attic | 31,4 | 32,1 | 27,3 | 25,8 |
| Outdoor | 18,9 | 17,8 | 17,8 | 18,9 |

The table shows significant decrease in the temperature between T3 and T4 for the attic. This is due to the exterior screen on the Velux window at the northeast and the automated control of the other screen. The average temperature drops 5°C, and the peak with almost 10 °C. The difference between T3 and T4 is due to the automated solar shading control. In T5 the new Velux Active app controls the opening of the Velux windows in the attic and the staircase shaft. This results again in a clear decrease of the temperature in the attic and the staircase shaft. However, we expected even higher decrease, but the family close these windows at night, due to security, reducing an effect of night cooling. In this warm summer period with high outdoor air temperature, ventilative cooling is only possible during night with lower air temperature, when the control system is turned off.

Energy consumption for heating is higher than the predicted value, mainly due to higher indoor temperature (about 21°C) than the setpoint used in the calculation (19°C). The average yearly energy consumption for heating (gas consumption) and domestic hot water is around 70 kWh/m2/year. The electricity consumption is slightly above moderate household use (+400 kWh). There is most likely a rebound effect as an explanation on year 1, and the energy consumption was reduced during year 2.

## CONCLUSION

In general, home satisfaction is very high. The family indicated that they are very happy with the indoor climate, such as the indoor temperature, air quality, and the automatic system. The health and sleep quality of the family has improved considerably since they moved into the RenovActive house. They also report that their family life, as well as social contacts outside the family, have greatly improved. During their daily life, few adjustments of the automatic system are operated by the family. One reason could be that the family indicates that they feel unqualified to make adjustments; they consider that the system is smarter than they are, not daring to overrule it. Another reasoning is that as long as the system does not interfere with their primary needs (privacy, mosquito bites, etc.) they tolerate it.

Finally, important learning is that the family operates the technical systems, as well as its adjustment possibilities, slightly different than the intended strategy. Consequently, the flexibility and robustness of the technical systems operating in the indoor environment are essential to accommodate the occupants' preferences. For example, a system detecting significant deviations from planned parameters could return to a default setting or provide feedback to occupants to allow them to make informed decisions.

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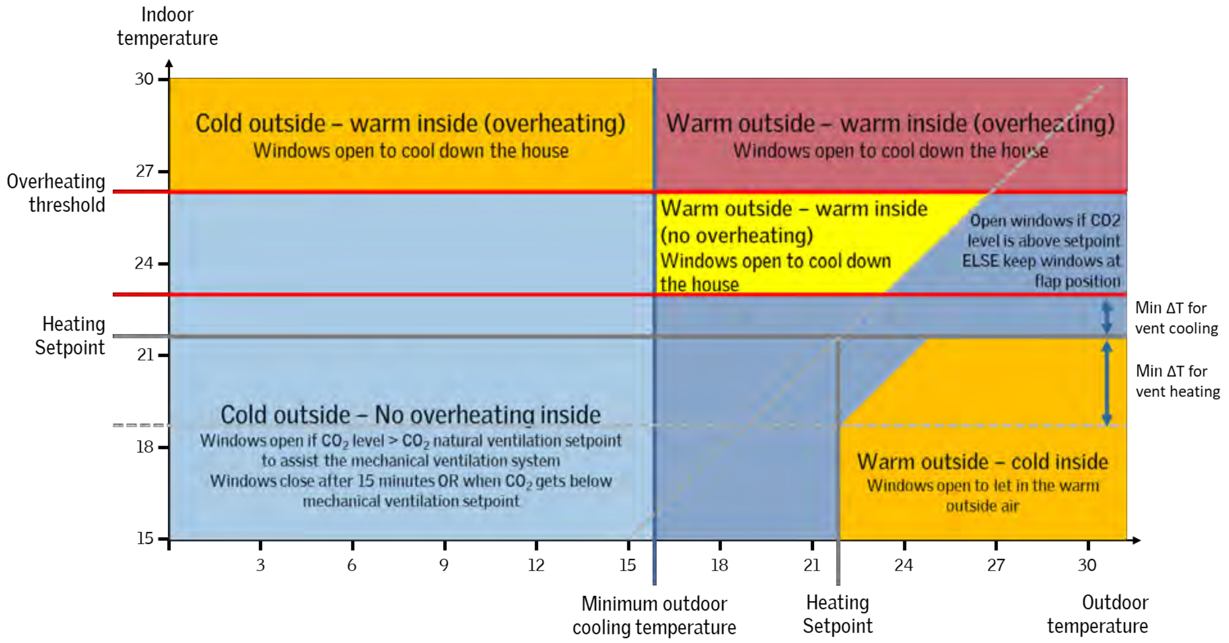


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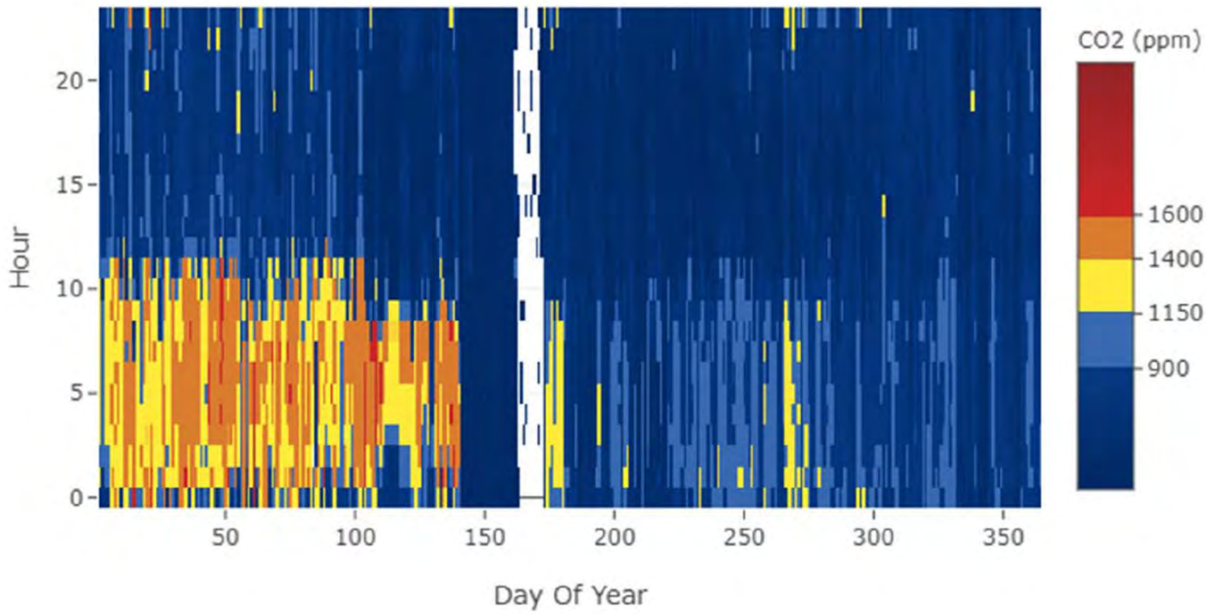


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