Calculation of the effect of ventilation measures in existing dwellings to reduce the carbon footprint

Wim Kornaat[1], Wouter Borsboom[1], Ruud van der Linden[1]

1 TNO, Molengraaffsingel 8, 2629JD Delft,
Netherlands

ABSTRACT

To reduce the carbon footprint of the built environment, a significant overhaul of the existing housing stock is essential. This entails not only ensuring proper insulation and airtightness in residences but also optimizing their ventilation systems. To precisely gauge the impact of an advanced ventilation system, the use of a pressure node model, such as multizone ventilation models like COMIS or TNO's AirMAPs model, is indispensable. However, when dealing with existing dwellings, numerous unknown variables, including interior door usage, can introduce substantial variations in results. A simplified approach can also lead to reduced calculation times. This paper employs a simplified approach, comparing advanced ventilation solutions in a specific dwelling based on limited building and user behaviour data. We present the current progress in modelling choices, and the initial results are promising. Initial results from the first comparison between the Dutch standard ventilation method (BKN) and the single-zone model are promising. When examining manually operated mechanical exhaust and natural supply systems (C1) alongside manually operated balanced heat recovery systems (D2), the ventilation flows align well. Furthermore, the CO2-controlled systems demonstrate a reasonable and as might be expected reduction of ventilation flows in relation to the actual CO2-control as being used .

KEYWORDS

Simulation, ventilation system, retrofitting, energy efficiency, indoor air quality, simplified one zone, multizone models

1 INTRODUCTION

To mitigate the carbon footprint of the built environment, a substantial transformation of existing housing stock is imperative. This involves not only ensuring proper insulation and airtightness in residences but also optimizing their ventilation systems. In recent years, there has been a surge in innovative ventilation solutions in the market, enabling precise timing and location of ventilation based on occupancy patterns. This leads to a significant reduction in overall ventilation and, consequently, reduced heating requirements.

Numerous programs are available for simulating heat losses and gains and indoor environmental quality in dwellings, ranging from basic RC networks to more advanced tools such as TRNSYS or EnergyPlus. To accurately evaluate the impact of an advanced ventilation system, a pressure node multizone ventilation model such as COMIS [1] or the AirMAPs model [2] [3] developed by TNO is indispensable. However, when dealing with existing dwellings, several unknown variables, such as interior door, can introduce substantial variations in results. A simplified approach can also lead to reduced calculation times. This paper adopts a simplified approach, comparing advanced ventilation solutions in a specific dwelling based on limited building and user behaviour data.

Moreover, there is a multitude of systems designed to recover heat or cold from exhaust air, subsequently using it to heat or cool supply air or provide hot tap water. To make informed decisions among these various ventilation system options and combinations for reducing the carbon footprint, it is crucial to understand their effects within a specific home. These effects depend on various factors, including the insulation quality of the building envelope, which influences the duration of the heating or cooling season. Additionally, factors such as infiltration and window usage play a pivotal role in determining heating and cooling demands. Furthermore, infiltration rates vary, depending on whether a balanced ventilation system or a system that creates over or under pressure is employed.

2 SIMPLIFIED MODELING APPROACH ENERGY AND IEQ

To achieve a precise evaluation of thermal comfort and energy consumption, it is imperative to employ a fine spatial resolution, involving multiple zones, in the modelling process, as opposed to using a single zone for a house. In our approach of reduced-order modelling, the primary focus is on employing a multizone RC-model (heat model). It's important to note that a multizone ventilation model demands a substantial number of input parameters and considerably extends the calculation time. Hence, we aim to integrate this multizone RC model with a one-zone ventilation model, a strategy that not only curtails the volume of required input parameters but also minimizes simulation time. The integration of models with different number of zones for the thermal and ventilation model necessitates a flexible coding framework for the comprehensive model.

2.1 Multizone RC network

In order to develop a more precise reduced RC model, we will employ a variety of standardized dwelling layouts that accurately represent the Dutch building stock. These layouts are visually depicted in figure 1 and encompass an apartment (or single-story dwelling) as well as 2-story or 3-story single-family houses. The number of thermal zones will range from 2 to 4, enhancing spatial detail. In the context of an apartment, a minimum of 2 zones is essential to replicate the influence of diverse room orientations. Typically, residents in the Netherlands tend to heat either the living room or, in some cases, both the living room and the bedroom, and occasionally even the attic. This leads to a maximum of 4 thermal zones. Each dwelling layout includes zones oriented in different directions, a crucial factor for investigating potential overheating issues.

For a specific dwelling, based on a pre-established Building Information Model (BIM), specifically gbXML in this case, an RC-model will be created [4], serving as a Building Energy Model (BEM). Given that both models function as network models, the transition from BIM to BEM is automated.

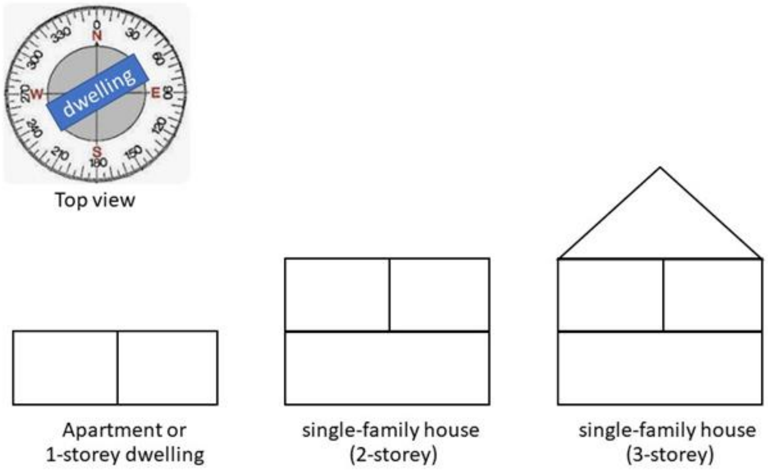


Figure 1: Reduced thermal model layouts characteristic for the Dutch building stock

2.2 Ventilation model

In order to reduce the number of input parameters of the ventilation model and reduce simulation time, we will implement a one-zone ventilation model, integrated with a multizone RC network. Within this model the ventilation features, including mechanical flows and ventilation grilles, based on the ventilation system, the envelope's leakages and the windows, will be automatically incorporated to align with the underlying multizone RC-model. This means, for instance, that the ventilation model includes envelope leakages and ventilation grilles, if present, for each zone within the thermal model. The ventilation flow in each zone is calculated by considering both the airflow through cracks, window openings, and grilles in the façade, as well as the mechanical ventilation provision within the zone. Figure 2 illustrates an example of the one-zone ventilation model for a mechanical exhaust system in a single-family house, with a 4-zone thermal RC-model delineated by a dotted line.

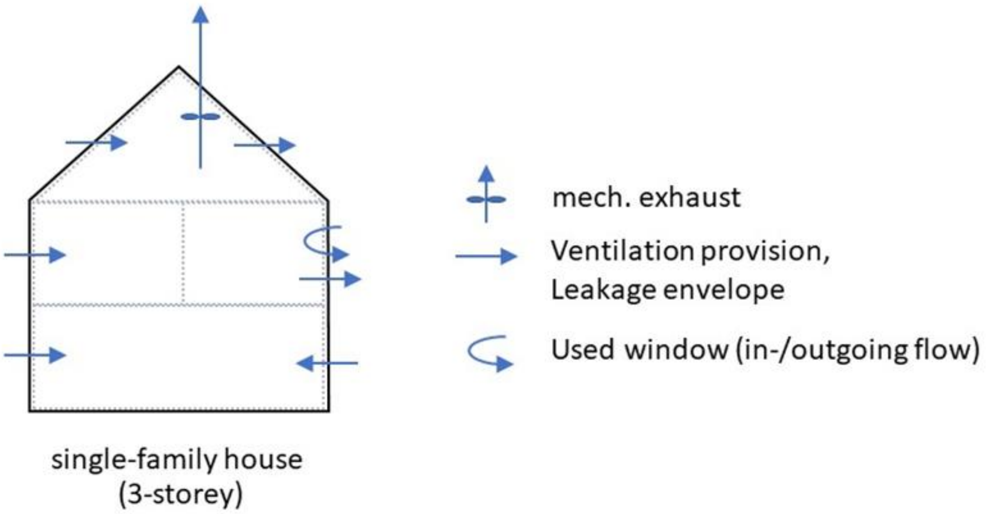


Figure 2: One zone ventilation model in combination with single-family house RC-model

2.3 Driving forces

The ventilation model will consider various driving forces, including wind pressures, thermal buoyancy and mechanical fans. To simulate wind pressures, we will create several sets of wind pressure coefficients tailored to different dwelling typologies, such as sheltered locations and non-sheltered locations. For thermal buoyancy, we will utilize the indoor temperatures calculated using the RC model and the placement of openings aligns with the BIM model.

2.4 Ventilation systems

We have integrated various types of ventilation systems and ventilation system controls into the ventilation simulation, all of which are commonly utilized in Dutch houses. Here are the details, including their respective names according to the Dutch Standard for energy performance building calculations (NTA8800):

a) Manual control of mechanical exhaust systems with standard grilles or self-controlled grilles based on 1 Pa (Type C2 and C2a).
b) Manual control of balanced ventilation systems (Type D2).
c) CO2-controlled exhaust systems (Type C4a and C4c).
d) CO2-controlled balanced ventilation systems (Type D3).
e) Fans (central or decentralized) with CO2 control on a per-room basis (Types C5b, D5a, and D5b).

These ventilation systems encompass the ones currently used in Dutch houses and those that can be implemented during renovations. They range from systems primarily operated manually to those equipped with room-level CO2 control.For the manual control of ventilation provisions, we extract data from schedules (time series). CO2 control is automatically simulated based upon the presence of individuals in various zones, as dictated by occupancy patterns.

2.5 Presence and occupant behaviour

The presence of individuals and their behavior regarding the manual use of ventilation systems, internal doors and windows is determined through schedules (time series). We employ hourly schedules for both weekdays and weekends. To model the utilization of ventilation systems and windows, multiple schedules are created, each assuming different usage patterns for these elements.

Regarding occupancy, it's common for people to be present for a few hours during the day or evening in the living room, and during the night in the bedroom(s). The number of bedrooms in use is determined based on the number of individuals in the household. This information is especially significant for CO2-controlled ventilation systems, where occupancy plays a crucial role.

2.6 Indoor Air Quality

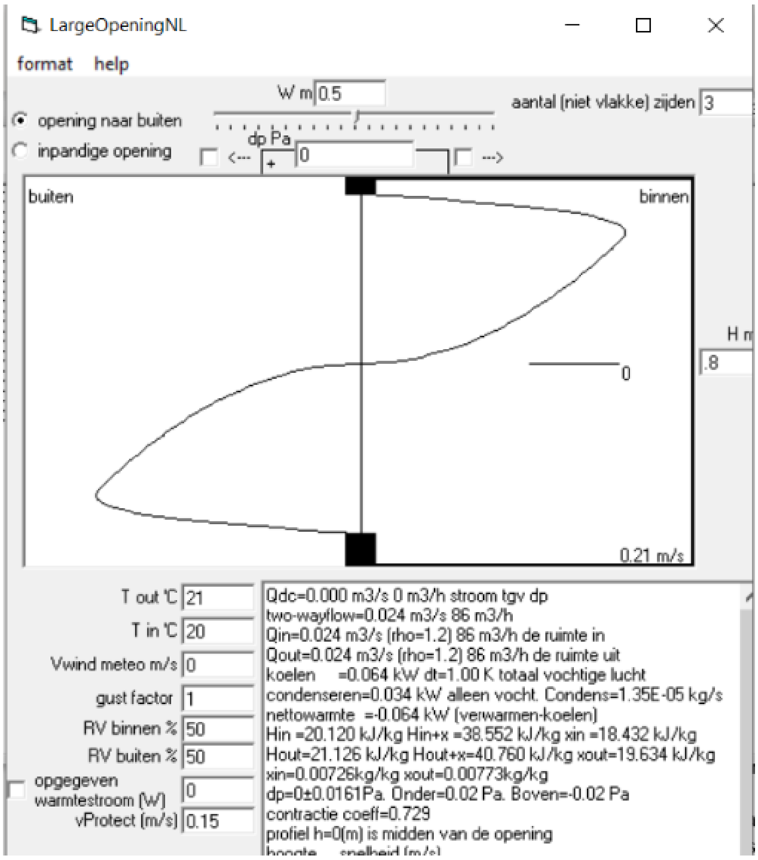
The RC-model encompasses the living and sleeping zones. By using the square meter data from the BIM file, the ventilation provisions are established in accordance with Dutch building standards for each thermal zone. This approach provides a clear understanding of the required ventilation for each zone when occupied. When combined with the concurrently simulated ventilation, it offers insights into indoor air quality throughout the simulated time period. When individuals are present in a thermal zone, we assess the Indoor Air Quality (IAQ). We calculate the IAQ by determining the ratio between the ventilation rate and the number of individuals multiplied by the required ventilation per person, which is fixed at 25 m^3/h and 70% of 25 m3/h during sleeping due to the lower metabolism.

Formula: IAQ(zone) = ventilation / (number of persons * 25 m^3/h)   (1)

As KPI is considered the percentage of time with IAQ < 1 (based on the time a person is present in a zone or in the dwelling).
In cases of exfiltration, we take into account the average pollution of the rest of the dwelling and use that to determine IAQ of room.

2.7 Window modelling

We will investigate the significance of turbulent air exchange, where both ingoing and outgoing airflow occur simultaneously when windows are open (as depicted in figure 3) [5]. This turbulent air exchange is influenced by factors such as the temperature disparities between the indoor and outdoor environments, as well as the dimensions and surface area of the window [6].



● opening naar buiten
○ inpandige opening

W m 0.5

aantal (niet vlakke) zijden 3

dp Pa ☐ <--- + 0 ☐ --->

H m .8

T out °C 21
T in °C 20
Vwind meteo m/s 0
gust factor 1
RV binnen % 50
RV buiten % 50
☐ opgegeven warmtestroom (W) 0
vProtect (m/s) 0.15

```
Qdc=0.000 m3/s 0 m3/h stroom tgv dp
two-wayflow=0.024 m3/s 86 m3/h
Qin=0.024 m3/s (rho=1.2) 86 m3/h de ruimte in
Qout=0.024 m3/s (rho=1.2) 86 m3/h de ruimte uit
koelen     =0.064 kW dt=1.00 K totaal vochtige lucht
condenseren=0.034 kW alleen vocht. Condens=1.35E-05 kg/s
nettowarmte  =-0.064 kW (verwarmen-koelen)
Hin =20.120 kJ/kg Hin+x =38.552 kJ/kg xin =18.432 kJ/kg
Hout=21.126 kJ/kg Hout+x=40.760 kJ/kg xout=19.634 kJ/kg
xin=0.00726kg/kg xout=0.00773kg/kg
dp=0±0.0161Pa. Onder=0.02 Pa. Boven=-0.02 Pa
contractie coeff=0.729
profiel h=0(m) is midden van de opening
hoogte     snelheid (m/s)
```

Figure 3: Turbulent air exchange open window

2.8 Internal door modelling

The state of internal doors, whether open or closed, has a substantial impact on ventilation flow, particularly when grilles or windows are open on both sides of a building. This consideration notably applies to bedroom doors. In the Netherlands, there are varying practices, with some individuals keeping them closed almost all the time while others leave them open frequently. The latter approach enhances cross-ventilation by exploiting pressure disparities created by wind affecting different building facades. We will explore scenarios with bedroom doors either consistently closed or consistently open.

In the case of closed internal doors, the ventilation model will account for additional resistance in the openings of ventilation grilles or windows. This approach addresses the typical challenges associated with ventilating bedrooms located on the leeward side of single-family houses.

2.9 Airtightness

The airtightness of a specific dwelling will be determined either through measurements, if available, or calculated in accordance with the Dutch NTA8800 standard, taking into consideration the construction year and the type/layout of the dwelling.

3 VALIDATION OF THE SIMULATION MODEL

Simulations are conducted using a ground-based row dwelling as the basis for comparison. These simulations are compared with simulations based on the multizone ventilation model COMIS, following a standardized Dutch method (BKN).

3.1 Comparison between simplified method and standardized Dutch method

A comparison is conducted using a typical row dwelling, considering both the standardized Dutch method (BKN) and the simplified method as shown in figure 4. In figure 4 the ventilation due to the ventilation system (without leakages) is given. The assessment involves scenarios for the simplified 1 zone model used by a household of 2 or 4 persons, utilizing a mechanical exhaust system with manual control and a grills in the façade (C1), as well as a manually controlled balanced ventilation system with heat recovery (D2). The ventilation flows in these scenarios align closely with each other.

Additionally, various other ventilation systems are evaluated using the simplified method, and the resulting ventilation flows appear reasonable or as might be expected. The reduction of the ventilation is in line with the reduction for the different ventilation systems according to the Dutch Standard to calculate the EPBD (NTA8800), this will be reported more extensive in future publications. Furthermore the following can be concluded:

- The flow with CO2-controlled systems (exhaust systems C4a, C4c and C5b and balanced systems D3, D5a and D5b) are substantial reduced in relation to the manual controlled systems (respectively C1 and D2).
- Systems C4a and C4c have the same flows in case of a household with 2 persons, because these 2 persons only use the zones equipped with CO2-control according system C4a (living room and main bedroom). So the CO2-control in the other zones in case of system C4c (living room and all bedrooms) is not used. With 4 persons however the ventilation with system C4c increases to some extend in relation to system C4a, because of the fact that in case of 4 persons also other bedrooms (besides the main bedroom) are used. Thus the ventilation increases using system C4c, but also the IAQ improves.
- System D3 has a very low ventilation. This is due to the fact that only the living room is CO2-controlled. When people use the bedrooms in case of system D3 the ventilation is not increased, while the system D5a and D5b have CO2-control in all bedrooms and thus increase the ventilation in case the bedrooms are used. The system D5a and D5b thus have a higher ventilation compared to system D3, but also a better IAQ. Overall the system D5a and D5b thus are better.

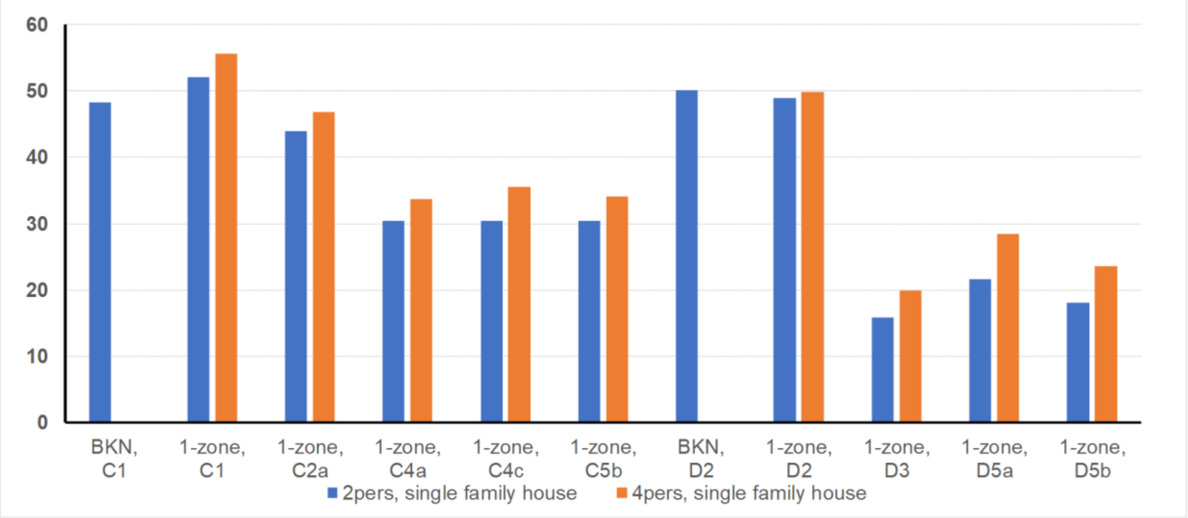


Figure 4: Average ventilation flows are compared in dm3/s between the standardized Dutch BKN method and the simplified 1 zone method for 2 persons and 4 persons household using manual controlled ventilation systems C1 and D2. Including calculations of the 2 persons and 4 persons household of the 1 zone ventilation model using different controlled ventilation systems (C2a, C4a, C4c, C5b, D3, D5a and D5b).

4 CONCLUSIONS

Initial results from the first comparison between the Dutch standard ventilation method (BKN) and the single-zone model are promising. When examining manually operated mechanical exhaust and natural supply systems (C1) alongside manually operated balanced heat recovery systems (D2), the ventilation flows align well. Furthermore, the CO2-controlled systems demonstrate a reasonable and as might be expected reduction of ventilation flows in relation to the actual CO2-control as being used, and these reductions are also in line with the Dutch Standard for EPBD Calculations (NTA 8800).

Additionally, more in-depth investigation is required to compare ventilation flows per zone calculated in a multi-zone model, with particular attention to the zoned ventilation system.

We will further research a one value KPI for IAQ to compare different renovation measures with end users.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

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