Implementation of a simplified model for natural ventilation in BE15

Master Thesis

Evelina Vladimirova and Francine Chittenden

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Supervisor: Per Kvols Heiselberg

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STUDENT REPORT

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[Evelina Vladimirova]

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[Francine Chittenden]

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By signing this document, each member of the group confirms participation on equal terms in the process of writing the project. Thus, each member of the group is responsible for the all contents in the project.

Danish Summary

Denne rapport sammenligner luftgennemstrømningen beregnet fra prEN 16798-7:2015 og integreret ind i BE15, med luftgennemstrømningen genereret af BSim. Begge modelleringsprogrammer bliver givet de samme input og betingelser fra et casestudie med varierende luftgennemstrømning fra fire forskellige vinduesmuligheder. Anvendelsen er tiltænkt afkøling om natten i boliger. Derfor er fokuseret på afkølingsperioden med vinduerne åbne og åbningen tilpasset i forhold til sikkerhedsaspekter.

Simuleringerne er udført for at beregne luftgennemstrømningen gennem vinduerne med forskellige åbningsarealer og for varierende vindstyrke, eksterne og interne temperaturer, vindstyrkekoefficienter og vindstyrketilpasningsfaktorer. To naturlige ventilationsprincipper er blevet behandlet; enkelt-siddet og krydsende.

De primære observationer er:

1. For enkelt-siddet ventilation:
    a. Den resulterende luftgennemstrømning er underestimeret i prEN 16798-7:2015 sammenlignet med BSim modellen.
    b. Simulationer viser at jo højere værdien for vinduets åbning er, jo mere er luftgennemstrømningen styret af opdrift.
2. For direkte krydsende ventilation:
    a. Input værdierne er ekstremt vigtige. Ellers bliver luftgennemstrømningen overestimeret
    b. Resultatet fra 128 beregninger viste at når parametrene var tilsvarende var den beregnede luftgennemstrømningen overestimeret i 6 tilfælde, mens de resterende var tilsvarende eller lavere end BSim luftgennemstrømningen. Dette viser at når alle parametre er tilsvarende kan beregningsmetoden foreslået i prEN 16798-7 leverer sammenlignelige luftgennemstrømninger i forhold til BSim.
3. SBi 213
    a. Resultatet fra simuleringerne har vist hvor de beregnede luftgennemstrømninger er i forhold til de anbefalede værdier fra SBi 213. Generelt underestimerer SBi 213 luftgennemstrømningen for enkelt-siddet med 260 til 440%, når det effektive åbningsareal dækker det anbefalede minimum. Yderligere, SBi 213 overestimerer med 49 til 75% når det anbefalede minimum for effektiv åbningsareal ikke er overholdt.
    b. For krydsende ventilation er luftgennemstrømningen underestimeret med 370 til 610% og overestimeret med 31 til 66%, når man tager højde for det effektive åbningsareal.
    c. Dette gør det tydeligt at se at BE15s luftgennemstrømningsberegning vil have fordel af at implementere en beregnet metode.

Baseret på resultatet fra analysen af simulationsresultaterne er der lavet anbefalinger vedrørende BE15s vejrdata fil og en omskrivning af software så den udfører beregning af luftgennemstrømningen om natten når der anvendes Familie-typen som bygningsparameter. Konklusionen fra denne rapport viser lovende resultater fra luftgennemstrømning beregnet via prEN 16798-7.

Preface

This thesis is in fulfilment for the requirements necessary in completing the Master's program in Building Energy Design with the Department of Civil Engineering at Aalborg University. It represents five months of intense focus and drive to uncover and investigate the topic thoroughly to satisfy the required amount of work to accomplish 30ECTS points.

The work commenced September 4th, 2017 and has actively been 'worked on' up until hand in the 10th of January 2018. This thesis will be defended on January the 22nd, 2018 in Aalborg, Denmark at an oral examination, with an external censor, that is open to the public.

Acknowledgment

This work has been supervised by Professor Per Heiselberg without whom, this thesis would not be in its presented form nor quality. His guidance, patience and insight into the topic and the process has been invaluable in the advancement of our research. His ability to ask just the right question to bring us "into the light" and provoke titillating discussions drove us to accept the challenges the data presented. We are truly grateful.

Reading Guide

The appendices are intended to be used alongside the report. An appendix has been labelled for example, Appendix A.1 to indicate that there is a part of Appendix A pertaining to a certain remark whereas 'Appendix A' without a following number would indicate that the entire Appendix is related to that particular comment.

In regards to citing sources, the Harvard method has been chosen and will appear as the author's surname and separated by a coma, the year of the publication within parentheses, (Surname, Year). The reference list will be arranged alphabetically starting with the source abbreviation and is presented at the end of the report.

Abstract

This report compares the airflows calculated from the prEN 16798-7:2015 and integrated into the BE15, with airflows generated from BSim. Both modelling programs are given the same boundary conditions from one case study varying the airflows through four window options. The application is in consideration for night cooling in residential buildings. Therefore, the cooling season is investigated with the window effective opening area being sized according to safety concerns.

Simulations have been done to calculate the airflow rate through the windows of varying opening area and for various wind speeds, external and internal temperatures, wind pressure coefficients and wind speed correction factors. Two natural ventilation principles were considered; single sided and cross.

The major findings are that:

1. For single sided ventilation:
    a. The resulting airflows from the prEN 16798-7:2015 are underestimated compared to the BSim model.
    b. Simulations show that the higher the value for the window opening free area, the more the airflows tend to be buoyancy driven.
2. For direct cross ventilation:
    a. The input values are extremely important. Otherwise, the airflows are overestimated.
    b. The results from 128 calculations showed that when the parameters were equivalent with each other, the calculated airflows in 6 calculations, were overestimated airflows while the remaining 122 calculations were equivalent or lower than BSim airflows. Showing that when all the parameters are similar the calculation method proposed in the prEN 16798-7:2015 can deliver comparable airflows to BSim.
3. SBi 213:
    a. The results from the simulations have shown a clear view on where the calculated airflows stand compared to the recommended values from the SBi 213. In general, the SBi underestimates the flows for single sided ventilation by 260 to 440%, when the effective opening area covers the recommended minimum. In addition, it overestimates by 49 to 75%, when the minimum for effective opening area is not met.
    b. For cross ventilation the airflow is underestimated by 370 to 610% and overestimated by 31 to 66%, considering the effective opening area.
    c. This makes it apparent, that the BE15 airflow calculations can benefit from the implementation of a calculated method.

Based on the results of the simulation analyses, recommendations are made in regards to the BE15 weather file and rewriting the software to perform night airflow calculations when using the Family-type building parameter. The findings in this report show promising results from the prEN 16798-7:2015 calculated airflows.

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Introduction 1

This chapter introduces the thesis. The general concepts that provoked the interest into the research paper. The energy directive, the software programs, the industry's current situation.

1. Project Motivation

The EU directive governing the energy performance of buildings (EPBD) has a few fundamental obligations it expects from member states. Of those obligations the one of importance to this report, is to develop methods of calculating energy consumption whilst utilising the EN ISO standards that have been developed concerning the calculation methodologies. The purpose is the pursuit to reduce the negative effect the energy sources have on the environment. (Roulet et al., 2006)

With that in mind, utilising natural ventilation principles such as night cooling is an economical choice in the pursuit of indoor air quality, thermal comfort, and lowering energy consumption in Denmark. However, as the building regulations become stricter and the newly built homes are made more and more air tight, the need for mechanical ventilation with heat recovery is increasing, as is the concern into the quality of the indoor environment. (Larsen et al., 2012)

This thesis investigates the simplified method of airflow calculations presented in the FprEN16798-7:2015 (16798-7), to see if it could be incorporated into the current energy compliancy program for Denmark, BE15, in regards to night cooling. The 16798-7 is an attempt to improve upon the airflow calculations presented in ISO 15242. (Carrié et al., 2015) Currently, the airflows are user defined in the BE15 program, with the aid of the SBi 213.

The SBi 213 accompanies the software program, as a user manual for guidance on the user defined inputs derived from the suggestions laid out in the ISO13790 and Danish Standard 418. Currently, the SBi 213 provides a range for a user defined natural ventilation, night cooling coefficient qn,nat. (Aggerholm et al., 2014) See chapter 6 for the SBi 213 recommendations.

The aim of this report is to apply a more sophisticated yet simplified method to calculate the natural ventilation coefficient qn,nat, in the BE15. Removing the user defined input for natural ventilation airflow and instead, providing a calculated result for the coefficient from the user defined inputs for the building elements, natural ventilation principles and parameters, and location.

The calculation methods presented in the 16798-7 proposal will be examined and tested to see if they can deliver the calculated airflows for qn,nat. The 16798-7 gives four methods in the consideration of airflow through windows. This paper investigates two of those methods; single sided calculations and cross ventilation with respect to inputs from temperatures and velocities.

To put the principles in practice, a reference building will be used as a case study from the Comfort House project. Please see chapter 4 for more details regarding the case study. The reference building will provide a base where the new parameters can be tested for their effectiveness and applicability.

1.1 Problem Formulation

The problem formulation for the report focuses on the main objective to validate that the airflow calculation method presented in the 16798-7 can be used in the BE15.

The airflows are dependent on the following parameters:

- Effective window opening area (from several types of windows)
- The natural ventilation principle used
- Temperature differences
- Wind velocities
- Wind pressure coefficient, Cp
- Terrain coefficients

The airflow results are finally compared to the current industry standard as suggested by the SBi213.

The primary research question:

> Does the implementation of the simplified model suggested in the 16798-7, succeed in delivering a method in which natural night cooling can be calculated as opposed to user defined, in BE15?

The research sub questions:

> Can the mean average monthly temperatures deliver favourable results when the airflows are buoyancy driven?
>
> Similarly, can the mean average monthly velocities deliver reasonable results when the airflows are predominately wind driven?
>
> Does calculating the natural ventilation using this method, give a better more realistic result compared to the user defined method currently used?
>
> How much extra is needed in the BE15 inputs to get the combined results with the integration of the 16798-7? Is this practical?

1.2 The Methodology

To accomplish this, the case study will be modelled in the two programs, BE15 and BSim. The case study provides the building's boundary conditions. By varying the window openings and styles, the calculation method is challenged in its flexibility of application.

After the models are validated, the following steps will be performed:

- Following the 16798-7 procedures, the values are entered into the 16798-7 spreadsheet
- Parameters for internal temperatures, external temperatures and roughness coefficients are considered and tried.
- Internal temperatures from the BE15 are tried.
- In the above process the final airflow from the 16798-7 is a steady state airflow from the result of manual iteration calculations using the room temperatures generated from the iteration process in the BE15.

- The resulting airflows from the 16798-7 are then compared against the airflows produced from BSim simulations.
- When the results do not match an investigation into the parameters is made.
- The differences are recorded.
- The process evolves until all parameters have been completely investigated.
- The results are compared and documented.

The method used to apply the previous steps, is as follows

Project Set-up

- Analysis of the external boundary conditions a.k.a. the weather file
- Analysis of the ventilation principles
- Analysis of the building's boundary conditions a.k.a. the case study
- Analysis of the varying boundary condition a.k.a. the windows
- Analysis of the SBi213
- Analysis into the 16798-7's methods

Model preparation:

- Preparation of the BE15 model
- Preparation of the BSim model

Implementation:

Single sided ventilation principle

- Implementing the 16798-7 airflows generated by parameter changes
    a. Internal temperatures:
        i. Internal Design temps from ISO13790
        ii. Internal Design temps from the Danish building regulations
        iii. Iteration using internal temps from the BE15 model
    b. External temperatures:
        i. Monthly Daily mean average temps
        ii. Monthly night mean average temps
    c. Roughness Coefficients:
        i. Calculated coefficients as recommended
        ii. Default coefficients
- Comparing the resulting airflows from the implementation process with airflows from BSim
- Analysis of the results
- Implementing suggestions from the preliminary results
- Final results for airflow values for single sided ventilation compared with BSim
- Room temperature results from the two programs compared.

Cross ventilation

- Implementing the 16798-7 airflows generated by parameter changes:
  Following the same simulation sequence as the single sided; three attempts apply the varying parameters:
- Attempt 1 consists of: Wind pressure coefficients from SBi 202, Monthly mean wind speed
- Comparing the resulting airflows from the implementation process with airflows from BSim
- Analysis of the results led to a second attempt.

- Attempt 2 consists of: Night average wind pressure coefficients from DRY 2013, Monthly mean wind speed
- Comparing the resulting airflows from the implementation process with airflows from BSim
- Analysis of the results led to a third attempt.
- Attempt 3 consists of: Night average wind pressure coefficients from DRY 2013, Monthly night mean wind speed
- Comparing the resulting airflows from the implementation process with airflows from BSim
- Final results for cross ventilation
- Room temperature results from the two programs compared.

Results and discussion:

- The single sided results compared to the current airflows from the SBi 213
- The cross results compared to the current airflows from the SBi 213
- Impact of the different parameters
- The new parameters proposed for usage in BE15

1.3 Delimitations

Limits geographically:

This research paper uses a weather file for Danish weather only. The limits of this file are discussed in chapter 2.

Limits from the case study:

Only one case study is considered in the report. Therefore, simulation models are designed from this particular building's geometry and location.

Limits in regards to the software programs:

The BE15 simulates the entire building as one thermal zone. There is no input parameter for the location of the building, i.e. city location or open terrain. The spreadsheet does not have the opportunity to enter the building's orientation. This is handled instead when the windows are entered and their respective cardinal directions are entered.

Night ventilation cannot be manually entered in the BE15 for a family home. Therefore, the type of building needed to be changed from Family to Other. This has other consequences as is explained in Chapter 8.

BSim is limited in its airflow calculations in the regards of not being able to calculate for doors and pulsating flows that often occur when a room is ventilated with single sided ventilation principles.

BSim has two modes to simulate models: single zone modelling (szm) and multi zone modelling (mzm). The researchers of this report chose szm over mzm because of their familiarity with the calculation process and understanding the results produced from the szm. When simulating single sided ventilation in BSim, the software only considers the windows placed on the same external façade. As seen in chapter 9, all zones are single sided ventilated with all but the living room, zone 8, having only one window on one external façade. Zone 8 has two windows on one external facade. In this regard, szm is appropriate because the airflows do not migrate through the other zones. In cross ventilation, however, one wants to simulate the airflow across the building from one external opening to the other. This is considered direct cross ventilation. To accomplish this in the szm, the entire building is simulated as one zone. The software will simulate the airflow from one side, the windward side, across the zone to the leeward side for each window opening on a façade ensuring mass balance. This is in line with the way that the 16798-7 simulates direct cross ventilation, as explained in chapter 7.

Limits to the ventilation principles:

The report investigates single sided and cross ventilation principles. Due to the case study being a single story building with no skylights stack ventilation is not considered.

This report is investigating the ability to night cool, therefore, only summer months will be considered. As can be seen in Figure 2, mean average monthly external temperatures, September is warmer than June is. Therefore, the months considered the cooling season are June, July, August and September.

Window opening considerations were chosen empirically, while considering safety concerns. Described further in chapter 5.

Relative humidity is not simulated nor considered in the parameters as the 16798-7 does not use relative humidity as an input and BE15 cannot simulate it.

Microclimate and Weather Considerations 2

2.1 Weather file and the Microclimate

When considering natural ventilation in the design of a building, the outdoor climate, and the building´s immediate surroundings, microclimate, play a crucial role in nature's ability to provide the airflow needed to penetrate into the building. The weather file used in Denmark for programs such as the BE15 and the simulation tool BSim, is the DRY2013 weather file as specified in the BR15. The use of this file became obligatory in January 2015. (BR15, 2015) DRY stands for Danish Reference Year. This file is an accumulation of weather data over a 10-year span from 2001-2010 and was published in 2013. The data is treated with the extreme weather conditions being removed in order to provide a general and consistent overview of the weather conditions that can be expected on average in Denmark. (Wang, P., et al., 2013)

The file used for energy calculations however, is comprised of three weather stations, 6156 Holbæk Flyveplads, 6184 DMI, and 6188 Sjælsmark. As seen in Appendix N, these three weather stations are positioned on Zealand. They do not represent an average weather prediction for all of Denmark. Instead, a discussion was made to have the weather file represent the most populated area in Denmark. (Wang, P., et al., 2013)

Naturally, there is the possibility to get a more localised weather file and insert that into the software. However, regular energy consultants use the weather file that accompanies the software program. Considering, the main objective is to see if the 16798-7 method of airflow calculations can be integrated into the BE15 program, it makes sense to use the standard weather file.

Temperature:

Natural ventilation is dependent on air pressure differences between the internal and external environments, provided by either temperature differences or the pressure differences caused by the wind and most likely, both occurring concurrently (Heiselberg, 2005). When considering the temperature differences, the airflow will be driven by thermal buoyancy. For this force to be dominant in regards to night cooling, the external night air needs to be below the internal air temperature. Figure 1 shows the monthly mean outdoor temperatures on a daily average in contrast to the mean average monthly nightly temperatures.

According to the ISO 13790, night cooling ventilation occurs when the internal environment for occupants reaches and/or exceeds 24 °C. When we compare this internal temperature to the mean average monthly night temperatures as shown in figure 1, we can see that there is a positive potential for night cooling due to the lower external temperature values at night.

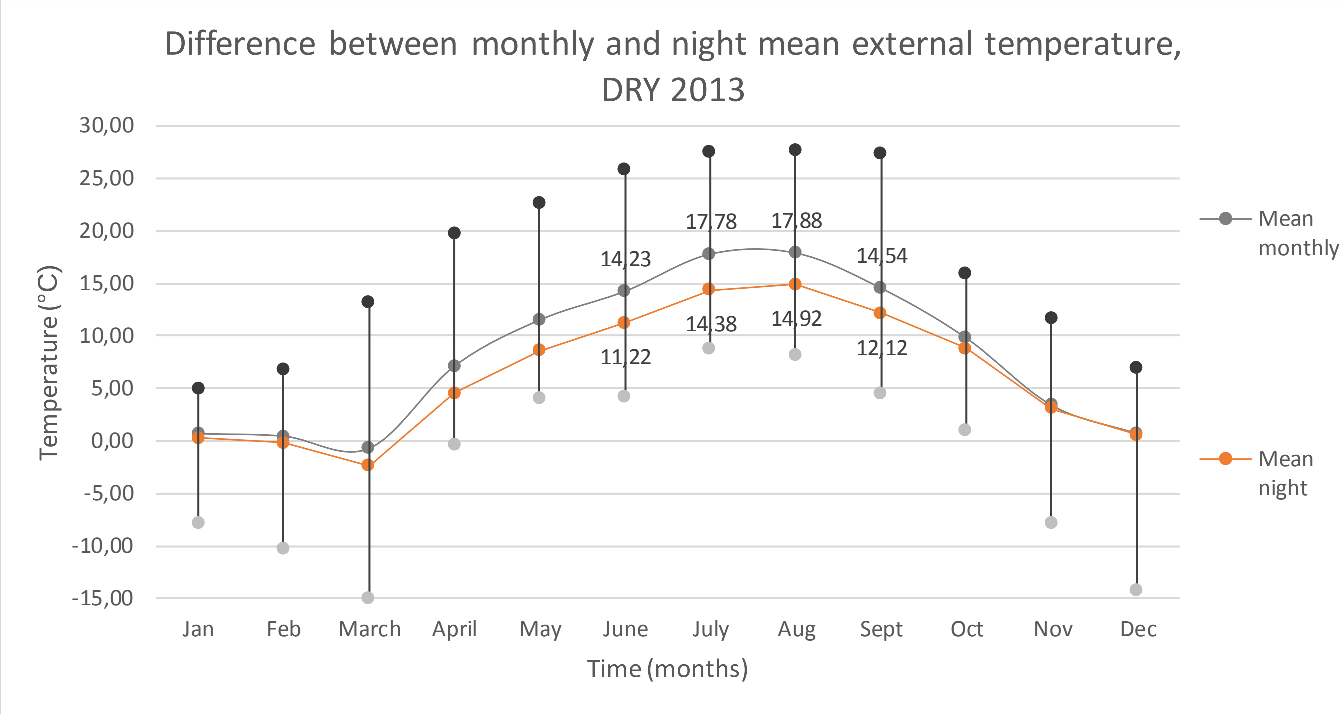

Figure 1-Difference between monthly and night mean external temperature, DRY 2013

2.2 Wind characteristics

The wind speeds in Denmark are measured at multiple weather stations at a height of 10m from the ground. (Wang, P., et al. 2013) These values are recorded and treated in much the same way as the temperature values previously described. In figure 2, one can see that the wind speed is quite consistent and measures in at a mean monthly average of approximately 4.4 m/s for the year. The wind can vary greatly and there are times when the wind velocity reaches 0 m/s.

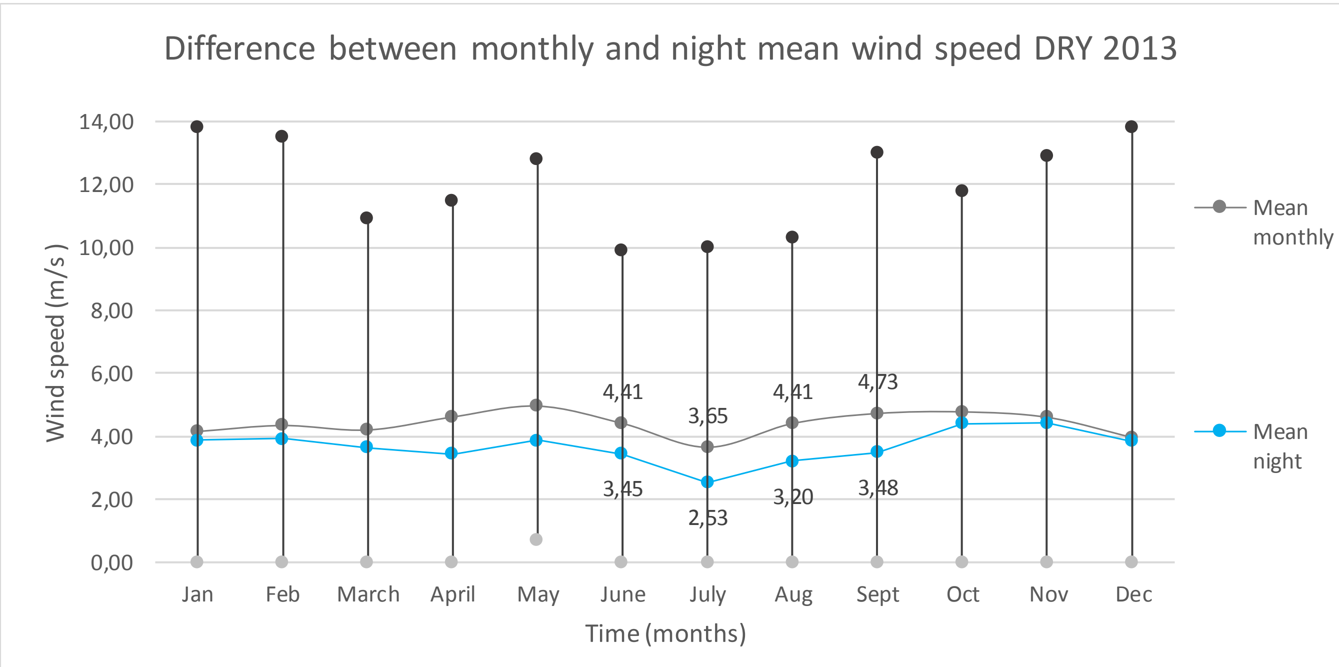

Figure 2-Difference between monthly and night average velocities, DRY 2013

The weather file also provides the winds' directions. These values are used in dynamic simulation tools like Bsim for the actual degree the wind is coming from. In quasi or periodic simulations like the BE15, these values are simplified into the eight general cardinal direction degree, i.e. North is 0/360° whereas, South is 180°. And so on.

2.3 The microclimate

The microclimate also plays a key role on the influence of natural ventilation from wind speed. The mean average monthly wind velocities, V10, are measured in an open area with no obstructions. This does not represent the area where the case study is built (please refer to chapter 4 the case study). The wind speeds are influenced by the terrain topography, k, and roughness, α. In the SBi 202, the meteorological wind speeds are treated with two coefficients k and α. The following expression can be used to calculate wind driven velocity at any height, Vh, and terrain type.

Equation 1

$$Vh = V10 * k * h^{\alpha}$$

Where,

K is the terrain coefficient and α is the terrain roughness coefficient as described in the following table.

Terrain type	k	α
Open flat country	0,68	0,17
Country with scattered shelter	0,52	0,20
Suburban areas	0,35	0,25
City centre	0,21	0,33

Table 1-coefficients used to calculate wind velocity on site. Source SBi 202

The wind pressure on a building is influenced by the building's surroundings, the building's surfaces, the topography of the location, the direction of the wind and the building's geometry. Taking this into consideration Orme, Liddament and Wilson's studies suggested wind pressure coefficients, Cp, for two building types, square with a ratio of external dimensions 1:1 and rectangular with external dimensions ratio of 1:2. (SBi202, 2002) These wind pressure coefficients are researched further in chapter 3, Natural ventilation calculation methods.

2.4 Parameters to be considered further in the report

Description:	Symbol	Unit	Value	Comments
Mean average monthly external temperature	θe	°C	Varied	DRY2013 file
Mean average external night temperatures	θe,n	°C	Varied	DRY2013 file
Wind speed at 10 m height	V10	m/s	4,0	Mean yearly average
Wind speed at building height	Vh	m/s		
Wind pressure coefficients	Cp	-	Varied	See appendix A
Terrain type	k	-	0,35	Suburban area
Terrain roughness	α	-	0,25	Suburban area

Table 2-Parameters to be considered further in the report

Natural Ventilation 3

This chapter describes, 'what natural ventilation is and its challenges'. Drawing upon previous work from other researchers, not only are the driving forces in natural ventilation described but so are the principles considered in this paper.

3.1 Introduction to natural ventilation

Natural ventilation in its simplest form can be achieved by simply opening a window. It can provide occupants with fresh air and can give a feeling of connection to the external environment without leaving the building. If strategically used, natural ventilation can play a key role in lowering energy consumption while contributing positively to the internal atmospheric and thermal comfort. (Heiselberg, 2005)

For the cooling season, natural ventilation can be used as a passive cooling concept to lower internal temperatures through night ventilation. This concept considers the lower external temperatures and encourages internal heat transfer through convection by providing an opening in the façade for the cooler air to enter the building and remove the internal room heat and the building's accumulated heat as it exits the building. How the airflow travels depends on the natural ventilation principle used. In the following figure, the three basic types of natural ventilation are presented; Single sided, cross, and stack.

According to (Larsen, 2006), stack ventilation is the most effective when combined with cross ventilation. This principle is best used in buildings where the openings are separated by one or more stories or with a minimum internal room height of 3,3m and where the outlet is placed higher and the inlet much lower, even as low as floor height. (Heiselberg, 2005) As is explained later in chapter 4, the case study is a single storey building. Therefore, stack ventilation will not be considered further in the report. Instead, a focus on airflows from single sided and cross ventilation are explored.

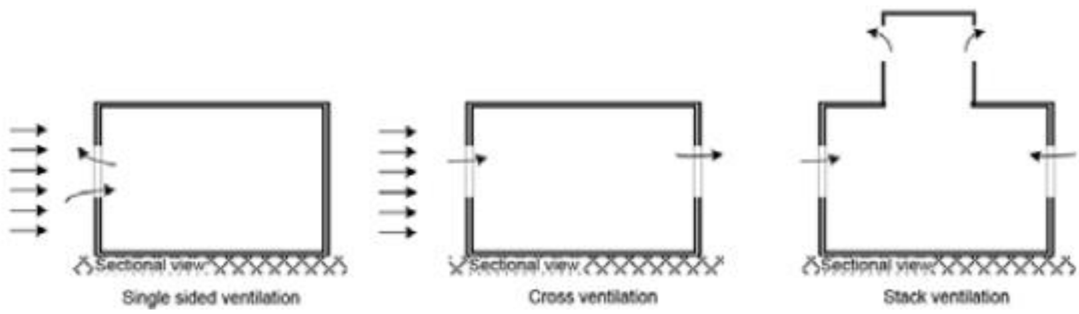

Figure 3-Natural Ventilation Principles - Source: SBi 202

For natural ventilation to work the windows or vents, need to openable. This can be done manually with the residents responsible for the natural ventilation control when they feel discomfort, or an automated system can be incorporated to ensure occupancy comfort at all times. The latter would require an energy source and increase energy consumption whereas the first option is dependent on the individual's personal feeling of discomfort, which could vary from other residents.

3.2 Driving forces in natural ventilation

Naturally ventilated buildings employ the airflow caused by pressure differences whether oblique, parallel or perpendicular, across and/or through the building envelope. These pressure differences are actuated by thermal buoyancy and wind pressure.

Thermal buoyancy:

The pressure differences in thermal buoyancy occur when the air densities between two or more spaces are not of equal value. With the assumption of steady state conditions within the building's environment, a constant external density and no wind pressure, the external and internal pressure distribution can be described as follows:

Equation 2

$$P = P_0 - \rho_0 g H$$

Where,

Subscript 0 is the reference or starting conditions,

P is the external or internal pressure [Pa],

P_0 is the pressure at the reference level (usually the floor) [Pa],

ρ_0 is the external or internal air density at a reference level [kg/m^3],

g is gravitational acceleration [m/s^2],

H is the height above the reference level [m].

If P_0 is used to refer to the external air then atmospheric conditions apply. Whereas for the internal air, P_0 is dependent on the mass of the internal air. The perfect gas law is used to determine its volume and temperature.

When considering the pressure difference Δp_t across an opening, the above formula is then applied to both the external and internal air. Here the coefficient z represents the height of the opening.

Equation 3

$$\Delta p_t = P_{u0} - P_{i0} - gz(\rho_u - \rho_i)$$

Where,

P_{u0} is the external reference pressure [Pa],

P_{i0} is the internal reference pressure [Pa],

ρ_u is the density of the external air [kg/m^3],

ρ_i is the density of the internal air [kg/m^3].

Under certain conditions, the differences between temperature and density are co related. Seen below, this expression can be used with temperature differences < 30K and if the air is incompressible. (Heiselberg, 2005).

Equation 4

$$\frac{\rho_u - \rho_i}{\rho_i} \cong \frac{T_i - T_u}{T_u}$$

Where,

Tu is the external temperature [K],

Ti is the internal temperature [K].

The neutral plane H_0 is a height where the pressure difference is equal to zero. For openings below the neutral plane, the pressure differences will be positive whereas the pressure differences will be negative above the neutral plane.

Therefore, the static pressure distribution can be expressed as:

Equation 5

$$\Delta p_t = \rho_i g \frac{T_i - T_u}{T_u}(H_0 - z)$$

In regards to single sided ventilation, where the vertical opening is located on one side of a zone, the horizontal neutral plane can be found between two openings placed above each other. The pressure difference under the neutral plane will be positive and the pressure difference above will be a negative pressure difference. If however, the neutral plane is found in the inlet, if the inlet area can accommodate, the flow below the neutral plane will be at a positive pressure difference and the airflow out will be through the same opening giving a bidirectional opening. The ratio of the opening areas; inlets and outlets, directly effects the location of the neutral plane.

Taking into consideration that the warmer air layer is thicker than the colder air layer, the total airflow, q [m^3/s], through the opening can be expressed as;

Equation 6

$$q = \frac{1}{3} A \sqrt{\frac{g(T_i - T_u)(H_t - H_b)}{T_i}}$$

Where,

A is the opening area [m^2],

H_t is the height of the top of the opening area above the floor [m],

H_b is the height of the bottom of the opening above the floor [m].

Consideration must be given for the streamline contraction, interfacial mixing, flow separation and viscous forces (Heiselberg, 2005). Therefore, the opening area A is replaced with the effective opening area A_{eff}. This product represents the empirical factor Cd, the discharge coefficient, multiplied by the original opening area, A. In this way the contraction of the flow through the opening and the friction loss are accounted for. The discharge coefficient is at a value of 1,0 when the openings are rounded. For sharp-edged openings the values are in the range 0,6-0,7. Therefore, if the value is unknown, 0,65 is value typically used. (Heiselberg, 2005)

For other ventilation principles, including cross ventilation, the total airflow rate through the window opening can be derived from the following expression:

Equation 7

$$qv = Cd * A\sqrt{\frac{2 * \Delta p}{\rho}} = Cd * A\sqrt{\frac{2 * \Delta T * g * |H_t - H_0|}{T}}$$

Here, the density is the density of the air passing through the opening. In this expression, the neutral plane is assumed to be outside the opening providing a unidirectional flow, with constant velocity through the opening. It should be noted that this is rarely the case with natural ventilation as the velocity of the wind fluctuates. Nonetheless, for simplification, the expression holds.

Wind Pressure:

Wind driven natural ventilation utilises the wind-induced pressure on the surface of the building to ventilate the interior. Not only the velocity of the wind but also the wind's direction, effects wind driven natural ventilation. To compensate for the obstacles that interfere with the natural flow, a wind pressure coefficient, Cp, is used. This dimensionless coefficient considers the building's shape, the surrounding terrain and the wind's direction. This leads to the following expression where the wind pressure, P_{wind}, is the product of the dynamic pressure and the Cp value.

Equation 8

$$P_{wind} = Cp * \frac{1}{2} * \rho_u * v_{ref}^2$$

It is important to keep in mind that the Cp values are derived from empirical methods. In this report, the Cp values represent the average for the side they represent. In this regard, a positive value for the windward side is the average of all the Cp values for that particular facade. This is where differences can appear because the windows are not necessarily placed in the façade where these Cp values occur. Therefore, when entering the values, it is important to know how the program will be utilising them and which Cp values the program uses for consistency in the results.

Another area of investigation, when using the above formula is to know what Vref the program is using. Some calculations are done with Vref being the velocity at 10m high and some are treated with the velocity at building height or Vsite. (Larsen, 2006)

With,

Equation 9

$$\Delta Pw = P_{wind} - P_{int}$$

The pressure difference across an opening can be calculated by the following expression, (Heiselberg, 2005),

Equation 10

$$\Delta Pw = Cp * \frac{1}{2} * \rho_u * v_{ref}^2 - P_{int}$$

In the above expression if the internal pressure is unknown, it can be determined through iteration. Otherwise, if the pressure difference across the building is of interest, as it is with cross ventilation, then the difference in Cp values can be used instead and the internal pressure, P_{int}, is removed from the formula to derive at:

Equation 11

$$\Delta Pw = Cp,w * \frac{1}{2} * \rho_u * v_{ref}^2 - Cp,l * \frac{1}{2} * \rho_u * v_{ref}^2 = \Delta Cp * \frac{1}{2} * \rho_u * v_{ref}^2$$

Airflows from wind driven ventilation:

Using the expression from Equation 7 for the airflow rate through an opening and inserting the expression Equation 10 from the wind driven airflow for an opening, as is the case in single sided ventilation, can be derived resulting in the following expression:

Equation 12

$$qv = Cd * A * \sqrt{\frac{2 * \left| Cp * \frac{1}{2} * \rho_u * v_{ref}^2 - P_{int} \right|}{\rho}}$$

It should be noted that ρ is dependent on the airflow direction used. So airflow into the building will use ρ_u , which is the density of the external air while airflow out of the opening will use ρ_i the air density of the internal air. (Heiselberg, 2005)

For cross ventilation, the following expression is done for each of the openings. (True, 2003)

Equation 13

$$qv = Cd * A * \sqrt{\frac{2 * \Delta P}{\rho}} = Cd * A * Uo\sqrt{|\Delta Cp|}$$

Here, ΔCp is defined as the Cp coefficient for the façade the window is located in minus Cpi. Cpi is defined as the internal pressure coefficient. Cpi can be found by the mass balance equation. All Cp values are dimensionless. [-]

Case Study 4

This chapter describes the case study that will be used to determine the effect from the introduction of the new airflows.

4.1 The Case Study introduction

The case study located at Stenagervænget 37, Vejle Denmark, is one of ten houses that was involved in a project called the Comfort House. (Larsen 2012) It was launched in 2007 as a collaborative development project with many contributors including Saint Gobain Isover A/S. The vision was a project that could convey passive house concepts with the combination of low energy housing principles. The mission was to publically announce the results of the project in the hopes of shaping the concept, construction principles and building regulations for low energy houses of the future.

After the buildings were erected, a measuring campaign was conducted by Aalborg University from 2008 to 2012 focusing on the indoor environment and energy consumption. From this campaign, we can see that there was a family of four that resided at this residence, which was comprised of two adults and two children. (Larsen, 2012)

From Figure 4, one can see that the house is located in a suburban area with an orientation of approximately 28 ° counter clockwise from North.

Figure 4-The case study located at Stenagervænget 37, Vejle (Source: Google maps and krak.dk)

The building has been designed as a square with external measurements reading 13.0m by 13.0m. (Please see Appendix B.4) The building stands 3.3m high from ground level. It is a single story, one family home designed with three bedrooms, an office, kitchen, dining room, living room, a utility room, powder room, and a family bathroom. The east entrance provides access to the hallway or living room, as seen in figure 5.

Throughout the report, these rooms have been grouped into zones dependant on the usage and placement (please see table 3). The rooms on the north side are zones 1 through 4. Their functions are mainly sleeping rooms with the exception of the office. The office could easily be made into another room if the family had the desire.

Zone	Function	Net area [m^2]	Room Heating
3 & 4	Bedrooms	10,4*2	Ventilation
2	Master bedroom	12,7	Ventilation
1	Office	11,4	Ventilation
7	Hallway	11,7	Ventilation
7	Entrance	3,5	Ventilation
5	Kitchen	10,3	Ventilation
8	Dining, Living room	36,2	Ventilation
6	Bath	5,3	Floor heating
6	Powder room	2,8	Floor heating
6	Utility room	4,1	Floor heating
	Total	118,9	

Table 3- Zone layout

The centre grouping of the wet rooms is also in its own zone. Zone 6 consists of the powder room, utility room, and family bathroom. This zone is heated by floor heating. This is the only zone with this type of heating. The kitchen is referred to as zone 5, dining and living areas are then in their own zone, zone 8. The last zone is the hallway and entrance area. This zone is referred to zone 7.

Figure 5-Case Study floor plan Source: Saint Gobain Isover A/S

Saint Gobain Isover A/S published a 260 page report entitled, Komfort Hus Bogen, on the entire Comfort House project from their perspective. (Isover, 2015) The building's constructions and installations are gathered in this report. From this report it is described that this building is constructed from prefabricated wooden elements with an external covering of white mortar. The inner walls are a combination of steel framed gypsum board walls and concrete elements. The concrete elements are found in zone 6 only. The concrete walls have a potential to keep the warmth due to their heat capacity and absorb internal gains to lower indoor temperature. However, from the accompanying pictures of the interior of the building one can see that the construction elements with a south-western exposure, are in fact nearly completely covered with kitchen cupboards and the eastern side has a built in closet near the entry way. By covering the heavy elements, direct solar gains are not in direct contact. The documentation states that the building is constructed with a thermal capacity of 132Wh/m2 K. However, by their own admission of the building's constructions, as stated earlier and seen in Appendix B.1, this is most likely around 80Wh/m2 K as described in the SBi 213. (Please see Appendix C.1)

The constructions that have influence on the building envelope and their respective u-values are in the table below.

Constructions	U-values [W/m2 K]	Ψ- values [W/m K]	Area [m2]
External walls	0,085		171,6
Roof	0,076		146
Terrain deck	0,068		138,7
Foundation		-0,043	47,4
Around doors/windows		0,000	
Interior foundation		0,03	25

Table 4-Constructions and their u-values

The windows are composed of 3 layers with argon gas between the panes. The frames are insulated wood/aluminium and are placed in the façade at a depth of 100 mm. (Appendix B.2)

Supplied again from Saint Gobain Isover A/S, is the following window parameters and their respective values. (Appendix B.2)

Windows	Ug [W/m2 K]	Uf [W/m2 K]	Uw [W/m2 K]	g-value
3 panes with argon gas	0,53	0,78	0,66	0,52

Table 5-window parameter values

For the most part, the installations for this house are rather common for the Danish building industry. Heating for zone 6 is supplied with floor heating. There is a 150m ground fed heat pump at this location that is used to supply heat to the floor heating. The unique installation for this house is that other than Zone 6, the ventilation air heats the rest of the house. The heat pump therefore also supplies the ventilation inlet with a heating coil, in order to warm up the external air. The air is heated to 18 °C here. If the air is to be heated further, the air-handling unit has a heat recovery system that tops up the temperature as needed. The air is supplied to the living room from channels under the floor and extraction is done from the roof in zone 6. (Please see Appendix B.3 for more details and diagrams.)

These installations are used later on in the report to build the simulation models in the BE15 and the BSim software.

Windows Study 5

This chapter describes the window openings and the choices thereof. It includes the calculation procedure for effective opening area and the corresponding parameters are introduced.

5.1 Purpose

In this paper different types of windows with different effective opening areas are used, in order to simulate air flow, and the effects from it during the night. Therefor the size of the opening area is in compliance with safety. The chosen types of windows have the ability to be opened during night time by means of burglar proof mechanism. The use of such mechanism restricts the opening allowance of the windows.

The following four types of windows are used in simulations with diverse opening areas, depending on what opening allowance the window type has, during night time.

5.2 Window types

a) Hopper window
Hooper is a window hinged to its frame at the bottom and opens at the top. It allows air intake by an opening area on the side and on the top. It opens to the inside.
This type of window opening strategy is further referred to in this paper as Option 1 and can be seen in simulation chapters. It has an opening depth of 0.1m. The effective opening area of the window is calculated according to its size as follows: width of 0.9m and height of 2m. The effective opening area of the hopper window includes two triangle areas on both sides of the window and one rectangle area on top. An assumption and a simplification is done in order to calculate the triangle area on both sides. The triangle was assumed to have a right angle. Option 1 hopper window has an effective opening area of 0.29m2. It is calculated by using the following formula:

Equation 1

$$A_{w,tot} = 2 * \left(\frac{1}{2}\, a_t * b_t\right) + (a_r * b_r)$$

Where:
Aw,tot – effective opening area
a_t- triangle side A
b_t- triangle side B
a_r- rectangle height
b_r- rectangle width
The full calculation can be seen in Appendix D.

Figure 6- Hopper window Source: https://i.pinimg.com/736x/26/5c/c8/265cc8c18a1d7bbed8f0fbe5dc2c341b--window-types-types-of.jpg

b) Casement window

Casement is a window hinged to its frame on the side. In this Case study it is assumed the window is a Single Casement window, meaning it has one opening part. It opens to the outside.

This type of window opening strategy is referred to as Option 2 and can be seen in simulation chapters. It has an opening depth of 0.01m. This type of window has two triangle openings on the top and bottom and one rectangle opening on the side the opening area of the window is calculated according to size as follows: width of 0.9m and height of 2m. This gives and opening area of 0.029m2 following the same calculation method as in section a) of the current chapter. A full calculation of the area can be seen in Appendix D.

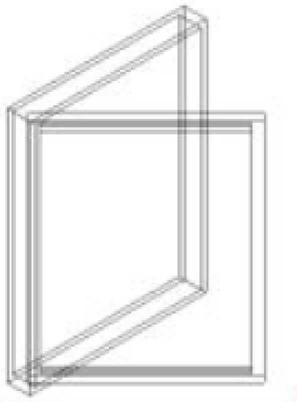

Figure 7-Casement window Source: https://i.pinimg.com/736x/26/5c/c8/265cc8c18a1d7bbed8f0fbe5dc2c341b--window-types-types-of.jpg

c) Awning window

Awning is a window hinged to its frame at the top and opens at the bottom. It allows air by an opening area on the side and on the bottom. It opens to the outside.

This type of window opening strategy is referred to as Option 3 and can be seen in simulation chapters. It has an opening depth of 0.005m. The effective opening area of the awning window includes two triangle areas on both sides of the window and one rectangle area on the bottom. The opening area of the window is calculated according to size as follows: width of 0.9m and height of 2m. This gives and opening area of 0.0145m2 and is calculated according to the method used in section a) of the current chapter. A full calculation can be seen in Appendix D.

Figure 8- Awning window Source: https://i.pinimg.com/736x/26/5c/c8/265cc8c18a1d7bbed8f0fbe5dc2c341b--window-types-types-of.jpg

d) Dannebrog window - Option 4

Dannebrog is a Danish type of Casement window. It has four opening parts- two at the top and two at the bottom. The openings at the top are smaller in size compared to the ones at the bottom. All openings are hinged to the frame at the side. The openings at the top are used for night ventilation. It opens to the outside and has a rectangle shape.

This type of window opening strategy is referred to as Option 4 in this paper and can be seen in simulation chapters. With this type of window it is assumed only one wing on the top side will be opened. The effective opening area of the window is calculated according to size as follows: width of 0.45m and height of 0.348m. This gives and opening area of 0.157m2. It is calculated by the following formula:

$$A_{w,tot} = (a_r * b_r)$$

Where:

Aw,tot – effective opening area

a_r- rectangle height

b_r- rectangle width

The full calculation can be seen in Appendix D.

Figure 9- Dannebrog window Source: http://bimobject.com/en/velfac/product/class_flags_type3

5.3 Window geometry

The building used for this Case study has different window areas and various placement throughout the building. On the table below could be seen detailed information on them and how the windows are referred to in this paper.

Window type	Height (m)	Width (m)	Area (m2)	Room placement	Zone	Orientation	Openable possibility
W1	2	0,9	1,8	Office	Zone 1	NW	Yes
W1.2	2	0,9	1,8	Master bedroom	Zone 2	NW	Yes
W1.3	2	0,9	1,8	Bedroom 1	Zone 3	NW	Yes
W1.4	2	0,9	1,8	Bedroom 2	Zone 4	NW	Yes
W2	2,2	3	6,6	Kitchen	Zone 5	SW	No
W3	2.1	2.5	5,25	Hallway/Entrance	Zone 7	NE	No
W4	2,2	4	8,8	Living room	Zone 8	SE	No
W5	2	3,5	7	Living room	Zone 8	SE	No

Table 6- Window characteristics and placement

As mentioned in above, windows in zone 7 and 8 do not have the ability to open. The openable windows in this case study are placed in zones 1 to 4 and have the same size. In order to simulate and calculate airflow for the whole building it was assumed windows in zone 7 and 8 have an openable section the same size as windows in zone 1 to 4. On the table below can be seen the parameters used in the calculation of the effective opening areas in the different options.

	Option 1	Option 2	Option 3	Option 4
Total window area (m2)	1,8	1,8	1,8	1,8
Window opening depth (m)	0,1	0,01	0,005	—
Calculated according to window size (m)	0,9x2	0,9x2	0,9x2	0,45x0,348
Window effective opening area (m2)	0,29	0,029	0,0145	0,1566

Table 7- Results for window effective opening area

SBi 213 Analysis 6

6.1 Current airflow and effective opening area recommendations from the SBi 213

The Sbi 213 provides guidelines and suggests values for airflow rates throughout the entire year. Due to the interests of this paper only summer period is taken into consideration. During the summer months, air flow is calculated as a function of window effective opening area, natural ventilation principle (NVP) and controllability of the windows. On the chart below suggestions for air flow rates can be seen, depending on hours of operation and window opening strategy.

Summer Conditions:

	Hours of operation		Night time cooling		In use 75% of the time during warm spells
Window control	Automatically controlled windows	Manually operated	Automatically controlled windows	Manually operated	Manually operated
Air flow (l/s/m^2)	1,8	1,8 *0,67 = 1,2	0,6	0.6*0.67= 0,4	1,2 * 0,75 = 0,9
ACR (per h)	3		1		
Ventilation type and effective opening area (%) of heated floor area	**Cross** ≥ 1,5 % **Single sided**≥ 4 %		**Cross** ≥ 1 % **Single sided**≥ 2 %		

Table 8- SBi 213 airflow recommendations

A calculation is done in order to see if the effective opening area of the different options used is enough for the current floor area for the night time cooling period. The window options that cover the minimum effective opening area are marked with red, they represent the window options covering the set minimum. Calculations for Option 2 to 4 can be seen in Appendix G.

Option 1 Zone	Heated floor area (m2)	NVP and min effective opening area (%)		Window size (m2)	Windows present in zone	Window effective opening area per window (m2)	Min effective opening area for zone (m2)	Actual effective opening area for zone (m2)
Zone 1	11,95	Single sided vent	2	1,8	1	0,29	0,239	0,29
		Cross vent	1				0,1195	0,29
Zone 2	13,38	Single sided vent	2	1,8	1	0,29	0,2676	0,29
		Cross vent	1				0,1338	0,29
Zone 3	10,95	Single sided vent	2	1,8	1	0,29	0,219	0,29
		Cross vent	1				0,1095	0,29
Zone 4	11,14	Single sided vent	2	1,8	1	0,29	0,2228	0,29
		Cross vent	1				0,1114	0,29
Zone 5	12,7	Single sided vent	2	1,8	1	0,29	0,254	0,29
		Cross vent	1				0,127	0,29
Zone 7	19,66	Single sided vent	2	1,8	1	0,29	0,3932	0,29
		Cross vent	1				0,1966	0,29
Zone 8	41,39	Single sided vent	2	1,8	2	0,29	0,8278	0,58
		Cross vent	1				0,4139	0,58
Building level	138,7	Single sided vent	2	1,8	8	0,29	2,774	2,32
		Cross vent	1				1,387	2,32

Table 9- Option 1 calculation of effective opening area

Option 1 for windows covers the demand set for one natural ventilation principle- cross ventilation. The area needed for night ventilation is less compared to the one used during occupied hours. As previously mentioned, the paper focuses on night ventilation, therefore values suggested for that time period will be compared to the results obtained during the study.

The air supply in the occupied rooms should fulfil the demand of no less than 0.3 l/s/m2 of heated floor area as per section 6.3.1.2 (1) for the BR15. SBi 213 suggests higher values to be used.

Zone	Heated floor area (m2)	Time of use	Air flow supply (l/s/m2)	Automatically controlled windows	Manualy operated	Air flow supply (m3/s)	
Zone 1	11,95	Night vent	BR15	0,3	0,3	0,004	
			Sbi 213	0,6	0,4	0,007	0,005
Zone 2	13,38	Night vent	BR15	0,3	0,3	0,004	
			Sbi 213	0,6	0,4	0,008	0,005
Zone 3	10,95	Night vent	BR15	0,3	0,3	0,003	
			Sbi 213	0,6	0,4	0,007	0,004
Zone 4	11,14	Night vent	BR15	0,3	0,3	0,003	
			Sbi 213	0,6	0,4	0,007	0,004
Zone 5	12,7	Night vent	BR15	0,3	0,3	0,004	
			Sbi 213	0,6	0,4	0,008	0,005
Zone 7	19,66	Night vent	BR15	0,3	0,3	0,006	
			Sbi 213	0,6	0,4	0,012	0,008
Zone 8	41,39	Night vent	BR15	0,3	0,3	0,012	
			Sbi 213	0,6	0,4	0,025	0,017
Building level	138,7	Night vent	BR15	0,3	0,3	0,042	
			Sbi 213	0,6	0,4	0,083	0,055

Table 10-Calculation of recommended airflow from SBi213 and BR15

Extraction from bathrooms, kitchens and utility rooms is mandatory in dwellings according to the Danish Building regulations. Kitchen hoods should extract 20l/s; bathrooms 15l/s and powder and utility rooms have an extraction of 10l/s. (BR 15 6.3.1.2). On the table below can be seen where extraction in the building is needed.

Room	Use	Area [m2]	NVP	Extraction	Zone
1	Kitchen	12.7	Cross + extraction	20l/s = 1,9 l/s/m^2	Zone 5
2	Bathroom	5,3	Extraction	15 l/s = 2,8 l/s/m^2	Zone 6
3	Wet rooms	6,9	Extraction	10 l/s = 1,45 l/s/m^2	Zone 6

Table 11-BR15 extraction airflow recommendations

For the case study, it is assumed that the extraction devices are off during the evening.

Analysis of the 16798-7 7

7.1 Analysis of 16798-7

16798-7, offers calculation methods regarding the ventilation for buildings when considering energy requirements. There are 2 overall methods to calculate airflows. The first method: “determination of air flow rates based on detailed building characteristics”, offers a manner in which ‘instantaneous’ air flow rates can be obtained dependent on the inputs which can be calculated for a variety of building components associated with the ventilation principle designed/considered for a particular building.

The second method, “Determination of air flow rates based on statistical approach” is intended to assist with the determination of airflow rates including infiltration at a national level. The procedure includes many case studies to accumulate data that can then be used locally, meaning at a national level in this European context, when considering airflow rates for EPD calculations. The first method from 16798-7 can be used in conjunction with method 2.

This report investigates method 1. From here the 16798-7 offers six more choices. This chapter and report focuses on the methods of calculations presented under “airflow due to window openings”. This chapter is then divided into four more methods of calculating airflows through window openings. It is here that two natural airflow principles are chosen: single sided ventilation and cross ventilation.

The calculations begin with an underlying assumption that the windows are in a single ventilation zone “the pressure of which at floor level can be considered as homogenous and equal to Pz,ref. “ (CEN/TC 156, 2015) Guidance to support this assumption is given in the technical report CEN/TR 16798-8.

The products considered need to conform to relevant EN product standards. The technical product data is then assembled and defined in accordance with 16798-7’s template provided in its Annex A.

The system design data includes the process design on an individual building basis. Is the ventilation mechanical or natural? Is it designed as balanced or exaction only? Perhaps it is designed as a supply air only system. The inputs are entered for the building’s individual requirements. This paper considers a mechanical system for the heating period and natural ventilation used as a cooling method in the summer season, as is the situation in the case study. Next, 16798-7 considers the control, operating conditions and physical and constants data.

After this initial input data gathering describing the unique operating conditions, the calculation procedure can begin.

Calculation procedure for Single Sided Ventilation:

The desired output for this research paper is $q_{V;arg;in}$. This value is calculated by the following equation;

Equation 2

$$q_{V;arg;in} = 3600 \times \frac{\rho_{a;ref}}{\rho_{a;e}} \cdot \frac{A_{w;tot}}{2} \cdot \max\left(C_{wind} \cdot u_{10;site}^{2} ; C_{st} \cdot h_{w;st} \cdot abs(T_z - T_e)\right)^{0,5}$$

Where,

$q_{V;arg;in}$ is the total airflow rate through the opening area into the ventilation zone [m3/h]

$\rho_{a;ref}$ is air density at 293K dry air and is used as a constant with a value 1,204 [kg/m3]

$\rho_{a;e}$ is external air density [kg/m3]

$A_{w;tot}$ is total window opening area [m2]

C_{wind} is a constant coefficient taking into account wind speed in airing calculations 0,001 [1/(m/s)]

$u_{10;site}$ is wind velocity at the site at a height of 10m [m/s]

C_{st} is a constant coefficient taking into account stack effect in airing calculations 0,0035 [(m/s)/(m*K)]

$h_{w;st}$ is useful height for stack effect for airing [m]

T_z is ventilation zone temperature [K]

T_e is external temperature [K]

abs stands for absolute

The constants in the equation are $\rho_{a;ref}$, C_{wind}, and C_{st}.

$A_{w;tot}$ is the total window area from all windows in [m2].

$$A_{w;tot} = \sum_{i=1}^{N_w} A_w \qquad \text{Equation 3}$$

To accomplish this requires the calculation of the window opening free area for each window. This is given by:

$$A_w = R_{w;arg} \cdot A_{w;max} \qquad \text{Equation 4}$$

Where,

$A_{w;max}$ is the maximum area the window can open [m2]

$R_{w;arg}$ is the ratio of window effective opening area to a maximum window opening area for an individual window. [-]

To determine the windows' effective opening area, please refer to Chapter 5, Windows.

To solve for the wind speed at site, 10m above ground, the meteorological wind speed is corrected using the following formula;

$$u_{10;site} = \frac{C_{rgh;10;site} \cdot C_{top;10.site}}{C_{rgh;met} \cdot C_{top;met}} \cdot u_{10} \qquad \text{Equation 5}$$

u_{10} is the meteorological wind speed that is manually inputted and for the purpose of this report derived monthly, from the DRY2013 weather file that both the BE15 and BSim simulation programs use.

From here, one can opt to either accept the default values from annex B table B.3.4.2. or calculate the 'C' coefficients according to ISO 15927-1. By choosing to calculate the coefficients, consideration is given to the roughness and topography near the building's site along with the meteorological station.

Wind speed correction factors:

Coefficient	$C_{\text{top;site}}$	$C_{\text{rgh;site}}$	$C_{\text{top;10.site}}$	$C_{\text{rgh;met}}$	$C_{\text{top;met}}$	$C_{\text{rgh;10;site}}$
Value	1	$C_{\text{rgh;10;site}}$	1	1	1	1,0/0,9/0,8*

*Table 12-Wind speed correction factors (source: Table B.3.4.2. FprEN 16798-7:2015) *please see the table below.*

Correction Factor $C_{\text{rgh;10;site}}$:

Terrain class, TER_CLASS	$C_{\text{rgh;10;site}}$
Open terrain	1,0
Country	0,9
Urban/City	0,8

Table 13- Correction Factor for terrain (source: Table B.12 FprEN 16798-7:2015)

$h_{\text{w;st}}$ is calculated using the following formula;

Equation 6

$$h_{\text{w;st}} = \max_{i=1 \text{ to } N_{\text{w}}}\left(h_{\text{w;path},i} + \frac{h_{\text{w;fa},i}}{2}\right) - \min_{i=1 \text{ to } N_{\text{w}}}\left(h_{\text{w;path},i} - \frac{h_{\text{w;fa},i}}{2}\right)$$

This factor is used to consider the height at which the buoyancy forces will be present.

$h_{\text{w;path},i}$ is the mid height of the window, relative to the ventilation zone floor level while $h_{\text{w;fa},i}$ is the height of the free area of the window. This latter coefficient is calculated by taking the effective opening area from windows and dividing it by the window width.

In analysing the initial equation, it is obvious that the formula considers either the external velocity or the temperature difference from external to internal ventilation zone temperatures. The maximum value from the two scenarios is then used in the formula to determine the airflow through the given window opening free area.

7.1.1 The wind speed correction factors:

The 16798-7 refers to the ISO 15927-1 in regards to calculating the wind speed correction factors. The 15927-1 handles the calculation principles in its chapter 7.2 Environmental influence on mean wind speed. The local environment is broken down into three factors; topography, ground roughness and nearby obstacles. In general, the mean wind speed is a function of these parameters.

The ISO 15927-1 has its own symbols. Therefore, a correlation between the two reports needs to be established.

The roughness coefficient C_R considers the effects on the mean wind speed at the site in regards to the height above the ground, and the roughness of the terrain. This latter condition takes into consideration the wind direction.

The roughness coefficient at height z is given by:

Equation A: $C_R(z) = K_R \ln(z_{min}/ z_0)$ for $z < z_{min}$

Equation B: $C_R(z) = K_R \ln(z/z_0)$ for $z \geq z_{min}$

Where,

K_R is the terrain factor [-] ;

Z_0 is the roughness height [m] ;

z_{min} is the minimum height [m]

The above three parameters are dependent on the terrain category as seen in the table below.

	Terrain category	K_R	Z_0	z_{min}
I	Rough open sea: lake shore with at least 5km fetch upwind and smooth flat country without obstacles	0,17	0,01	2
II	Farm land with boundary hedges, occasional small farm structures, houses or trees	0,19	0,05	4
III	Suburban or industrial areas and permanent forests	0,22	0,3	8
IV	Urban areas in which at least 15% of the surface is covered with buildings of average height exceeding 15m	0,24	1	16

Table 14- Roughness Factors from the ISO 15927-1

Please note, "if there is a change of roughness upwind of a site within a kilometer, the smoothest terrain category in the upwind direction shall be used." (ISO 15927-1:2003)

The coefficients from the 16798-7 that need to be defined on the left side of the following table followed by which equation is used to calculated the coefficient. Next, the parameters are defined and the last column holds the calculated value for the respective coefficient.

16798-7	15927-1						
	Equation	Z	Terrain Category	K_R	Z_0	Z_{min}	$C_R(z)$
$C_{rgh;site}$	A	3,3 m	III suburban	0,22	0,3	8	0,722
$C_{rgh;10;site}$	B	10 m	III suburban	0,22	0,3	8	0,771
$C_{rgh;met}$	B	10 m	I open	0,17	0,01	2	1,174

Table 15-the results for the roughness coefficients with the ISO symbol and the corresponding 16798-7 symbol

The topography coefficient "accounts for the increase in the mean wind speed over isolated hills and escarpments (not undulating nor mountainous regions) and is related to the wind velocity upwind to the hill. It shall be considered for locations; a. more than half way up the slope of a hill, and/or within 1,5 times the height of the cliff from the base of a cliff." (ISO15927-1:2003 pg 17)

It is defined by:

CT = 1	for $\Phi < 0{,}05$
CT = 1 + 2sΦ	for $0{,}05 \le \Phi < 0{,}3$
CT = 1 + 0,6s	for $\Phi > 0{,}3$

The case study does not fall within these parameters and therefore, the value of 1 is used for the coefficients $C_{top:site}$ and $C_{top;met}$ in the 16798-7.

Calculation procedure 16798-7 for Cross ventilation:

The calculation method used in the 16798-7 for direct cross ventilation through a window using wind velocity and temperature differences as inputs is defined below:

Equation 7

$$q_{\mathrm{V;arg;in}} = 3600 \times \frac{\rho_{\mathrm{a;ref}}}{\rho_{\mathrm{a;e}}} \cdot \max\left(C_{\mathrm{D;w}} \cdot A_{\mathrm{w;cros}} \cdot \min\left(u_{10;site}; u_{10;site;\max}\right) \cdot \left(\Delta C_{\mathrm{p}}\right)^{0,5}; \frac{A_{\mathrm{w;tot}}}{2} \cdot \left(C_{\mathrm{st}} \cdot h_{\mathrm{w;st}} \cdot abs\left(T_{\mathrm{z}} - T_{\mathrm{e}}\right)\right)^{0,5} \right)$$

In comparison to the single sided ventilation formula from section 7 equation2, the different parameters presented here are:

$C_{D,w}$, $A_{w,cros}$, $u_{10,\,site,max}$, and ΔCp.

$C_{D,w}$ is the discharge coefficient for windows. It is an empirically derived, dimensionless number, which considers the smoothness of a window's opening area. Values are found within the range of 0,6 to 1; 1 being completely smooth- offering little resistance.

$A_{w,cros}$ is the equivalent windows area for cross ventilation in m2.

$u_{10,\,site,max}$, is defined as the maximum wind velocity at site at 10m height for cross ventilation in m/s.

ΔCp is defined as the "difference of wind pressure coefficients between the windward and leeward sides", (CEN/TC 156, 2015). This parameter is dimensionless and the 'validity interval' is defined as 0 to 2.

$A_{w,cros}$ is determined by taking the smaller value from calculating the following formula once for $A_{w,cros,1}$ and again for $A_{w,cros,2}$.

Equation 8

$$A_{\mathrm{w;cros}j} = \frac{1}{4} \times \sum_{\substack{j=1\mathrm{to}\,4 \\ A_{\mathrm{w;ori},j}>0}} \left(\frac{1}{\sqrt{\frac{1}{A^2_{\mathrm{w;ori},j}} + \frac{1}{\left(A_{\mathrm{w;tot}} - A_{\mathrm{w;ori},j}\right)^2}}} \right)$$

Here we are introduced to a coefficient $A_{w,ori,j}$. This parameter takes into consideration the windows orientation and window angle. A copy from the 16798-7 can be found in Appendix O.

$U_{10,site,max}$ is not defined further in the 16798-7. It is assumed that it can be calculated from the u10,site value minus the correction factors for the site. In the input values table it has a predetermined value of 3m/s as suggested in the ICEE report (Carrié et al., 2015).

ΔCp is derived from table B.6 in the accompanying annex to the 16798-7. Depending on the shielding class the table has defined wind pressure coefficient values. To ensure that the ΔCp is considered, a preset value of 0,75 has been chosen. This coefficient represents a building under 15 m height, in a normal shielding class without skylights.

7.1.2 The results:

Single sided ventilation simulated with Case Study parameters:

In consideration of the single sided night ventilation, the four window options were considered over the cooling season from June to September. The geometry used in the inputs was extracted from the case study documentation. The external temperatures were extracted from the DRY2013 weather file.

The following table shows the input parameters and their respective values for each of the 16 calculations. The last lines in the tables show the resulting airflow calculations that will be transferred to the BE15 workbook.

DZT+MAET		**Option 1**				**Option 2**			
Symbol		**June**	**July**	**Aug.**	**Sept.**	**June**	**July**	**Aug.**	**Sept.**
Te		287,38	290,93	291,03	287,69	287,38	290,93	291,03	287,69
Tz		297,15	297,15	297,15	297,15	297,15	297,15	297,15	297,15
U10		4,4	3,7	4,4	4,7	4,4	3,7	4,4	4,7
Rwarg		0,16	0,16	0,16	0,16	0,016	0,016	0,016	0,016
Hpath		1,35	1,35	1,35	1,35	1,35	1,35	1,35	1,35
Hwfa		0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32
Hz		2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Nw		8	8	8	8	8	8	8	8
Nwdiv		1	1	1	1	1	1	1	1
Crghmet	default	1	1	1	1	1	1	1	1
	calculated	1,17	1,17	1,17	1,17	1,17	1,17	1,17	1,17
Crghsite	default	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	calculated	0,72	0,72	0,72	0,72	0,72	0,72	0,72	0,72
Crgh10site	default	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	calculated	0,77	0,77	0,77	0,77	0,77	0,77	0,77	0,77
Ctopmet		1	1	1	1	1	1	1	1
Ctopsite		1	1	1	1	1	1	1	1
Cttop10site		1	1	1	1	1	1	1	1
Awmax		1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
Aw		0,288	0,288	0,288	0,288	0,0288	0,0288	0,0288	0,0288
Aw tot		2,3	2,3	2,3	2,3	0,23	0,23	0,23	0,23

Cp		0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Win flow calc		Direct single	Direct single	Direct single	Direct single	Direct single	Direct single	Direct single	Direct single
Vent sys op		Natural op	Natural op	Natural op	Natural op	Natural op	Natural op	Natural op	Natural op
Hwst		0,32	0,32	0,32	0,32	0,03	0,03	0,03	0,03
Qvin	calculated coefficient	425,28	343,52	376,22	418,93	37,15	31,63	37,62	39,73
B.3.4.2	default coefficient	452,55	385,25	458,3	483,92	45,25	38,53	45,83	48,39

Table 16-16798-7 input parameters for option 1 and 2

DZT+MAET		**Option 3**				**Option 4**			
Symbol		**June**	**July**	**Aug.**	**Sept.**	**June**	**July**	**Aug.**	**Sept.**
Te		287,38	290,93	291,03	287,69	287,38	290,93	291,03	287,69
Tz		297,15	297,15	297,15	297,15	297,15	297,15	297,15	297,15
U10		4,4	3,7	4,4	4,7	4,4	3,7	4,4	4,7
Rwarg		0,0081	0,0081	0,0081	0,0081	0,087	0,087	0,087	0,087
Hpath		1,35	1,35	1,35	1,35	2,176	2,176	2,176	2,176
Hwfa		0,016	0,016	0,016	0,016	0,174	0,174	0,174	0,174
Hz		2,5	2,5	2,5	2,5	2,5	2,5	2,5	2,5
Nw		8	8	8	8	8	8	8	8
Nwdiv		1	1	1	1	1	1	1	1
Crghmet	default	1	1	1	1	1	1	1	1
	calculated	1,17	1,17	1,17	1,17	1,17	1,17	1,17	1,17
Crghsite	default	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	calculated	0,72	0,72	0,72	0,72	0,72	0,72	0,72	0,72
Crgh10site	default	0,8	0,8	0,8	0,8	0,8	0,8	0,8	0,8
	calculated	0,77	0,77	0,77	0,77	0,77	0,77	0,77	0,77
Ctopmet		1	1	1	1	1	1	1	1
Ctopsite		1	1	1	1	1	1	1	1
Ctop10site		1	1	1	1	1	1	1	1
Awmax		1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
Aw		0,01458	0,01458	0,01458	0,01458	0,1566	0,1566	0,1566	0,1566
Aw tot		0,12	0,12	0,12	0,12	1,25	1,25	1,25	1,25
Cp		0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05
Win flow calc		Direct single	Direct single	Direct single	Direct single	Direct single	Direct single	Direct single	Direct single
Vent sys op		Natural op	Natural op	Natural op	Natural op	Natural op	Natural op	Natural op	Natural op
Hwst		0,02	0,02	0,02	0,02	0,17	0,17	0,17	0,17
Qvin	calculated coefficient	18,81	16,01	19,05	20,11	202	171,97	204,57	216,01
B.3.4.2	default coefficient	22,91	19,5	23,2	24,5	246,07	209,48	249,2	263,13

Table 17--16798-7 input parameters for option 3 and 4

7.1.3 Discussion of the results:

There is an obvious difference in the resulting airflows dependant on the wind speed correction factors. The default values trend results in a higher airflow in all cases. The default values use the same wind speed for both U_{10} and U_{site}.

The calculated values for the wind speed correction factors are 16 – 18% lower than the default results.

Preparing the BE15 model 8

8.1 BE15 process

The process of simulating in the BE15 is done using the Compliance Program's Spreadsheet tool as opposed to the usual Software Program Tool. This allows an opportunity to see the numerical calculations that are running in the background of the software program and provides a unique opportunity to see the individual effects that occur by changing values in certain parameters in the background calculations.

Being constructed in a spreadsheet format, the workbook consists of 7 sheets that have an opportunity for input and 11 sheets for data calculations and reference data used in the calculations with one sheet providing the results.

a) Establishing outdoor Boundary conditions

The outdoor boundary conditions are given in the workbook as the weather file DRY2013. The weather file consist of values for average monthly solar radiation by azimuth angle, mean average monthly external temperatures, mean average monthly wind speeds, and the average monthly/hourly illuminance in Lux.

b) Establishing the building's boundary conditions

The building's boundary conditions are entered as values on the corresponding input sheets in the workbook. The geometry provided in the case study and window sections and be seen from the architectural drawings that were used for measurements in Appendix B.4.

The input sheets with short descriptions are as follows:

<u>Hoved</u>: On the 'Hoved' sheet, the building's overall square meters are entered [m2], heat capacity [J/K] and function (F means a residential building and A means other). From here, a determination depending on the function, of how many hours a week the building is in use, with 168 being always, is entered along with the hours of usage, eg 0-24 for a residential building. Noticeable omission compared to the software program is the field to enter the building's orientation.

Basic heat supply method to heat the building is entered on this page whether it be district central heating, a boiler, or heat pump for example. The inputs in this regard depend on the heating system of the building.

Room temperatures are entered here any temperature inputs that will be used in the calculations.

<u>Fordel</u>: this sheet provides the inputs in regards to how the systems are distributed throughout the building. For example, if you entered a heat pump on the 'Hoved' sheet, here is where the external pipes running in the ground and their heat loss will be accounted for. The water tank and its size, and input/output temperatures are entered. Etc.

<u>Konst</u>: this step is to input the building's geometry. Using the architectural drawings quantities are taken out in regards to the building envelope's constructions. The values for windows and doors are ignored in this sheet. These values are entered into the spread sheet along with the Uvalues, and design temperatures. There is a temperature factor, b, which considers the effect that the outside temperature has on the boundary condition. The outdoor surface temperature can differ from that

of the outdoor air temperature and that the internal surface temperature can vary from the internal room temperature. For example, a slab on grade floor with floor heating is more likely to transfer heat if the external surrounding's temperatures drop. Therefore, this component would have a b factor of 1. The same floor construction without floor heating is less likely to transfer the same amount of heat to the external environment. Therefore, this floor would have a b factor of 0,7. Given the same area multiplied by the constructions uvalue and then subsequently the appropriate b factor, the unheated floor would have a 30% reduction in heat loss compared to the heated floor. The building envelope constructions can be seen in the following figure. It should be noted that the areas for windows and doors are not taken out of the areas for these external constructions.

Vindue: This next step is to document the windows and doors. The windows orientation is recorded along with the many parameters. In regards to the shadows, a separate sheet is to be filled in. Returning to the 'Vindue' sheet the appropriate shadow area is inputted.

Skygger: this sheet accounts for the shadows on the windows, whether they be from an overhang, neighbouring building, obstruction in the yard, or the window recess itself.

Uopv rum: the program calculates the building as one thermal zone. The only time it considers an adjacent room is if it is unheated. This could be a basement in practice.

Vent: this stands for ventilation. This sheet provides an area where values for airflow from mechanical and/or natural contributions can be recorded for the calculations. There is consideration for ventilation in the winter and summer months. Infiltration should also be entered on this sheet.

Intern: intern is short for internal gains. Where the solar gains will be considered due to the window area and type of glass in the 'Vindue' section, this section considers the heat gains from people, appliances/equipment and lighting. In residential buildings, the lighting is not calculated.

Results: after the inputs are made for the specific parameters, the results can be viewed on this page. The overall heating required for the year, transmission and ventilation losses, overheating hours, and electrical consumption broken down by installation, ie. Heat pump, ventilators, domestic hot water etc.

8.2 BE15 Modelling Assumptions:

Following the process described in the section above, the Family model was entered into the BE15 spreadsheet. This model should then have provided the background for the BSim model. However, due to input constraints in the spreadsheet, the family type model had to be changed to Other Type A. Under the family type model, there is no option to enter night ventilation in a mechanically ventilated family home. This is because the house is considered always in use. (Please see appendix E.5 for a detailed explanation into the BE15 calculation methods)

By choosing other type A, the model can now accept inputs for night ventilation. However, Other Type A now calculates the internal gains differently than the Family Type. Here, the gains from people are only considered during the day when the building is in use. To overcome this, the evening equipment loads were increased until the combined totals from people and equipment gave equivalent totals to the family model.

The model had to be changed one more time, and the mechanical ventilation at night and infiltration at night needed to come out. This led the way to the final BE15 model, Preflow. To add the airflow at night in the BE15 spreadsheet the same field is used for both infiltration and night ventilation. To get just the night airflow, the infiltration was taken out.

Weather data:

DRY2013 is the climatic weather file used for all simulations.

Constructions:

The constructions are entered from measurements taken from the architectural drawings. The uvalues are entered from information provide from material as explained in the case study section, chapter 4.

Windows:

The values for the windows are taken from the case study material as described in appendix E.4.

Infiltration:

In the validation family model and the type Other A model, infiltration, qi, is included at 0,058 l/s/m2 . The value is from material provided as explained in the case study section. The value of 0,3 l/s/m2, q50, was provided from a blower door test. This value is then treated in the following formula as directed from the SBi213:

Equation 9

$$qi = 0{,}04 + 0{,}06 * q50$$

However, for the simulation of night ventilation, the infiltration at night is taken out.

Ventilation:

The mechanical ventilation was measured according to the Komfort Hus document as 142m3/h, which provides less flow than the BR demands. The demand is 0.3 l/s/m2 and the mechanical ventilation provides 0,286 l/s/m2. It is turned off in the night in the Pre flow type model.

Thermal bridges:

All thermal bridges for windows doors and the foundations have been entered.

Natural ventilation:

Natural ventilation is only simulated for night cooling with values coming from the 16798-7 airflows.

People Load:

The people load is entered at 1,5 W/m2 as suggested in the SBi213 for the Family model. In the Other type A model and the Preflow model, the program does not calculate a people load in the evenings when it believes the building is not in use. This results in a lower internal gain from this type of contributor. To compensate the equip load is increased.

Equipment load:

The equipment load is added at 3,5 W/m2 as recommended from the SBi 213 in the family model. However, under the Other type A and Preflow models, the equipment use at night was increased to accommodate for the difference in the contribution ti the internal gains from this type of heat source. Please see appendix E for additional details on BE15 calculation method.

Solar gains:

After running the BSim model a few times the solar gain contribution was very low. To offset this, the decision was made to change the g-value from 0,52 to 0,7 in both programs.

A complete list of parameters is available in the Appendix E.4.

8.3 BE15 Validation

To validate the models, the Family model was assumed accurate. The following Other Type A model was then validated to the results from the Family model. The key figures can be seen below were the family model and the other type A are identical. After the mechanical ventilation is turned off in the Preflow model, a savings in energy consumption is seen in the key figures. Considering we are not investigating the energy consumption this is deemed acceptable.

In order to validate Other - Type A, the internal gains had to be increased because in a family home the building is running 100% of the time. This is reflected in the β coefficient. The β value for Other - Type A is 0,67. Which means that the internal gains in the evening when the program thinks the building is not in use, needs to be considered. As shown earlier in chapter 6.1.2 the parameters are nearly the same. The results are seen below.

Because of the calculation methods within BE15 in regards to infiltration, the night time infiltration was set to zero. Due to the fact that night cooling principles are wanted, the mechanical cooling at night was set to zero.

Discussion:

In the Preflow calculations, there is an energy savings from the ventilators. The value has fallen from 2,2 to 1,5 kWh/m^2. Because the report is focusing on airflows and not the energy savings from night cooling, this result has no effect on the airflow rates and is therefore, dismissed.

Key figures		Family	Other Type A	Preflow
		[kWh/m2 yr.]	[kWh/m2 yr.]	[kWh/m2 yr.]
Contribution to energy demand				
	Heat	0,0	0,0	0,0
	EL. For operation	12,3	12,3	11,7
Net needs				
	Space heating	3,8	3,8	3,8
	Hot water	17,5	17,5	17,5
	Cooling	0,0	0,0	0,0
Special electrical needs				
	Heating of rooms	0,0	0,0	0,0
	Heating of water	0,9	0,9	0,9
	Heat pump	9,2	9,2	9,2
	Ventilators	2,2	2,2	1,5
	Pumps	0,9	0,9	0,9
Performance from special sources				
	Heat pump	21,3	21,3	21,3
	Total EL	42,9	60,6	60,0
Total energy requirement		30,7	30,7	29,2

Table 18-Keyfigures from the BE15 for model validation

Preparing the BSim model 9

9.1 BSim - The process

The process of simulating in BSim is done by using the Software tool, version 7.16.1.19. Study on the calculation methods and inputs is done by using the BSim Help file and can be seen in Appendix M.

a) Establishing outdoor Boundary conditions

The weather file used in the software simulations is DRY2013. The weather file consists of direct and diffuse solar radiation, external temperature, wind speed, given as an hourly value. Site properties such as ground reflectivity and emissivity are entered, as well as horizon angle.

b) Establishing the building's boundary conditions

The building's boundary conditions are entered using the geometry provided in the case study and window sections. The geometry is represented as a complete 3D building model. Constructions and components are assigned to the model using a Database, allowing to create a detailed model of the building. Windows in this software tool are simulated as one whole piece. Therefore, the opening area for the different simulation options is represented as a ratio of the effective opening area to the maximum window opening area.

The following figure compares how the building's zones are divided in BSim to the architectural drawings. For simplification, the angles in zone 6 are simplified into a rectangle of similar area. Built in cabinetry is not drawn in BSim.

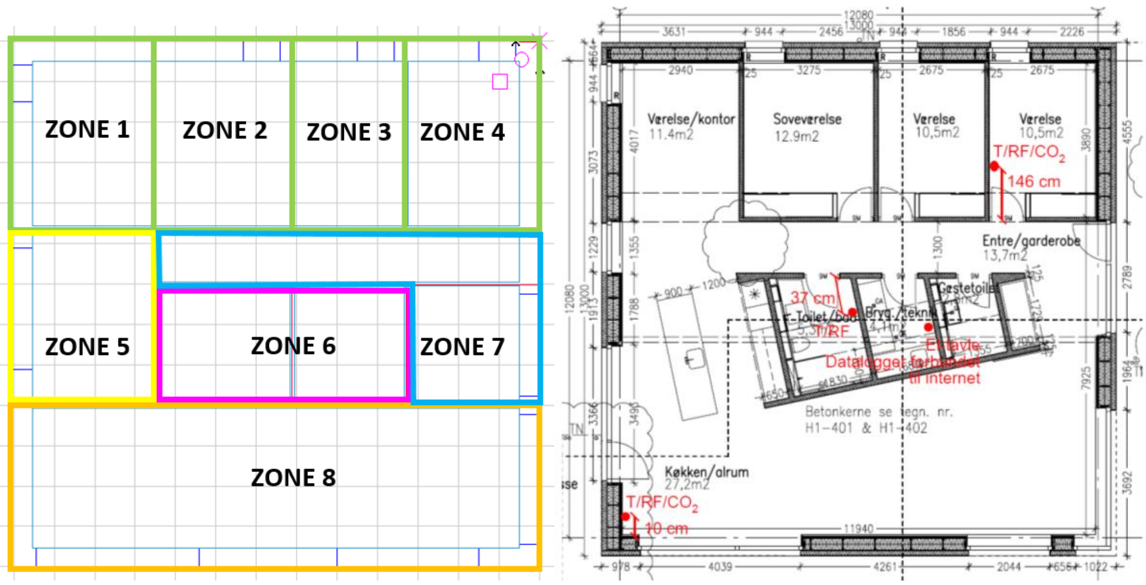

Table 19- the BSim zone division and the Architectural floor plan(Larsen et al., 2012)

9.2 Modelling Assumptions:

Weather data:

DRY2013 is the climatic weather file used for all simulations.

Geometry:

The building is modeled at 13m by 13m with an overall building height of 3,3m. The geometry falls in line with that specified in the case study. The following figure is taken from a southeasterly angle.

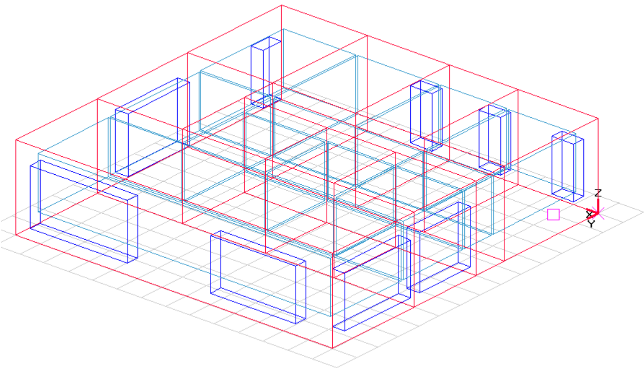

Table 20- BSim model showing the 3D geometry

The internal layout in BSim will not be identical to the architect's floor plan. It is a simplification for the program to simulate the internal environment.

Constructions:

The constructions are from a data base made by Rasmus Jensen Lund. Some changes were needed to ensure that the uvalues were the same as the constructions entered for the BE15 model.

Windows:

The opening area for the windows was modified for zone 5, 7 and 8 as the original windows in these zones did not open. The windows are very large. Therefore, the opening areas were made proportional to the overall window size. These calculations can be seen in Appendix D.

Discharge coefficients:

The discharge coefficients are all the same at 0,67.

Infiltration:

In the validation model, infiltration is included. However, in the BSim models for the simulation of night ventilation, the infiltration at night is taken out of the schedules and is not included in the calculations.

Ventilation:

The mechanical ventilation is turned off in the night during the summer months in order to simulate the effects from the night cooling natural ventilation flows.

Thermal bridges:

All thermal bridges for windows doors and the foundations have been entered.

Natural ventilation/venting:

This feature is activated in the venting system. Natural ventilation is only simulated for night cooling.

People Load:

The people load is assumed to be 4 people. They are given the same heat contributions whether children or adults and the same activity level. The internal gains from this contributor is adjusted to match the BE15 outputs.

Equipment load:

The equipment load is added with schedules to reflect the gains from BE15.

Solar gains:

After running the model a few times the solar gain contribution was very low. To offset this, the decision was made to change the g-value from 0,52 to 0,7. This change was modelled in the BE15 as 0,7 as well.

9.3 Comparison of BE15 and Bsim

The BE15 energy compliancy program, calculates the energy performance of buildings using monthly calculations based on a quasi-steady state calculation method. Dynamic effects are considered by introducing correlation factors based on usage. (Le Dreau et al., 2013)

BSim also uses a quasi-steady state method in its calculations, which uses hourly or semi hourly data supplied from the same weather file as the BE15. However, this state is applied to each time step in a finite number of steps. The conditions are assumed to be constant from the end of one time step to the beginning of the next. The program is considered a dynamic simulation program in the regards of the amount of calculations, and consideration occurring at each time step. Furthermore, the time steps are supported by nodes in the constructions with co relating control volumes. In this manner, the more time steps that are simulated the closer the results should relate to reality.

	BE15	BSIM
Thermal simulations	The building is simulated as one thermal zone.	The building is arbitrarily divided into thermal zones.
External building conditions	N/A	Input parameters: Terrain site i.e. urban, city etc. Ground type including temperature External surrounding's emissivity Reflected light Horizontal degree
Solar considerations	Values from the weather file is monthly mean solar radiation in kWh/m2 per month, from the 8 cardinal directions dependent on the glass areas' vertical position, 90° or 45°. A zero° input leads to one value for each month.	Direct solar radiation is calculated every ½ hour based on the actual position of the sun. Diffused radiation is distributed in the room and to surfaces according to a chosen weight factor. Reflective solar weighted value.

Solar gains	The amount of solar radiation transmitted through the glassed area into the thermal zone.	The amount of solar radiation transmitted through the glassed area minus the lost radiation from ex. curtains and minus the radiation lost to other thermal zones.
Internal gains	Two contributions entered manually; people 3.5W/m2 and equipment 1.5W/m2 for a family home	Contributors are entered under systems for each zone with an arbitrary amount of W/m2 entered and is accompanied by a schedule and control schedule.
Heat transmission through constructions	Uses the formula and dimensioning temperatures recommended in the DS418. A*U*ΔT=Heat transmission surface resistances are considered from the table in the DS418.	The constructions have control volumes and nodes for each surface and one in the middle of each layer. As the heat is transmitted through the materials, the temperature from the last node becomes the starting temperature for the next. The starting indoor zone temperature is the air temperature plus the effect from the radiation from the surrounding surfaces in the zone.
Occupancy	Relative service life Type of building i.e. family or other	Detailed hourly schedules
Heat flow	N/A	Heat flow from a surface is calculated with the convective heat transfer coefficient and the longwave heat exchange.
Infiltration	Is affected by the occupancy/relative service life	Inputs under each thermal zone with control schedules entered as air change rate.
Constructions	Entered without a material list	Is accompanied by a database of materials and their individual densities and thermal capacity values.
Building's heat capacity	Entered from a table in the SBi213	Calculated from the materials entered in the database and used in the model for the constructions.
Building's geometry: Height Gross floor area Net floor area	 N/A Input parameter Input parameter derived from the ground slab	 Input parameter Calculated from the drawn model Calculated from the gross area minus the construction area.
Internal temperature	DS418 20°C or set points suggested in the ISO13790	The very first simulation starts at 20°C until a steady state condition is reached and then the temperature of the room is the operative temperature. The

		default is that the air temperature is 50% of the operative temperature. This value can be adjusted by the user.
Ventilation Mechanical ventilation	Inputs made based on suggestions from the SBi213 Amount of time it is running uses a F0 input for the utilization factor. Entered as above with built in set points as described in Appendix E.5.	Inputs are made under the systems for each zone. Amount of time it is running is controlled in schedules by hour. Entered with arbitrary values by the user.

Table 21- comparison of the calculation methods from BE15 and BSim

For a thorough analysis of the two programs calculation methods, please see Appendix E.5 – BE15 calculations methods and Appendix M – BSim calculation methods.

9.4 Validation procedures Bsim

The validation procedure in this report is made in comparison to a BE15 excel sheet calculation model Other - Type A representing 'Other' type of buildings. As previously mentioned, BE15 model with a residential Type F does not take night ventilation into consideration in the calculation method, due to the usage hours of the building. Consequently type F is switched to type A, and adjusted to have the same total energy requirement, net heating, cooling and electrical needs. Furthermore, it is used to simulate the effect for night ventilation and compared do the dynamic simulations from BSim.

A focus on the validation are losses from transmission and ventilation, and gains from solar radiation, people and equipment. A measure of uncertainty is considered acceptable, because of the different calculation methods and detail level behind the software and spreadsheet tools. The overall key numbers are aimed to be within a 5% range of difference. Important parameters for further use and interest from BSim simulations are change in operative temperature and airflow.

The two models used in the validation procedure follow the same geometry, have the same constructions and components. Results from the validation can be seen in the table below.

SS model	Sum/Mean	Range for validation		+/- 5% (MWh)	1 (31 days)	2 (28 days)	3 (31 days)	4 (30 days)	5 (31 days)	6 (30 days)	7 (31 days)	8 (31 days)	9 (30 days)	10 (31 days)	11 (30 days)	12 (31 days)
Solar Radiation BE15	13,581	12,902	14,260	0,679	0,311	0,566	1,165	1,600	1,806	1,661	1,835	1,717	1,359	0,916	0,393	0,251
Solar Radiation BSim	11,016	**11,016**			0,213	0,481	0,975	1,315	1,432	1,329	1,478	1,405	1,142	0,791	0,317	0,137
Equipment BE15	8,167	7,759	8,575	0,408	0,694	0,627	0,694	0,671	0,694	0,671	0,694	0,694	0,671	0,694	0,671	0,694
Equipment Bsim	8,142	**8,142**			0,693	0,625	0,691	0,670	0,692	0,669	0,693	0,691	0,669	0,693	0,669	0,692
People load BE15	1,480	1,406	1,554	0,074	0,126	0,114	0,126	0,122	0,126	0,122	0,126	0,126	0,122	0,126	0,122	0,126
People load Bsim	1,464	**1,464**			0,124	0,112	0,124	0,120	0,124	0,120	0,124	0,124	0,120	0,124	0,120	0,124
Transmission loss BE15	-10,325	-9,808	-10,841	-0,516	-1,278	-1,159	-1,315	-0,880	-0,689	-0,540	-0,373	-0,374	-0,528	-0,804	-1,104	-1,281
Transmission loss Bsim	-15,978	**-15,978**			-0,854	-0,982	-1,376	-1,648	-1,691	-1,654	-1,613	-1,599	-1,548	-1,214	-0,875	-0,924
Ventilation loss BE15	-2,743	-2,606	-2,880	-0,137	-0,410	-0,375	-0,443	-0,249	-0,154	-0,086	-0,005	-0,003	-0,079	-0,194	-0,334	-0,410
Ventilation loss Bsim +	-2,521	**-4,644**			-0,021	-0,083	-0,198	-0,225	-0,308	-0,309	-0,526	-0,471	-0,231	-0,193	-0,077	0,121
Infiltration Bsim	-2,123				-0,155	-0,153	-0,215	-0,232	-0,250	-0,154	-0,156	-0,150	-0,153	-0,201	-0,154	-0,151
Total Ventilation BSim loss	**-4,644**															

CV model	Sum/Mean	Range for validation		+/- 5% (MWh)	1 (31 days)	2 (28 days)	3 (31 days)	4 (30 days)	5 (31 days)	6 (30 days)	7 (31 days)	8 (31 days)	9 (30 days)	10 (31 days)	11 (30 days)	12 (31 days)
Solar Radiation BE15	13,581	12,902	14,260	0,679	0,311	0,566	1,165	1,600	1,806	1,661	1,835	1,717	1,359	0,916	0,393	0,251
Solar Radiation BSim	11,016	**11,016**			0,213	0,481	0,975	1,315	1,432	1,329	1,478	1,405	1,142	0,791	0,317	0,137
Equipment BE15	8,167	7,759	8,575	0,408	0,694	0,627	0,694	0,671	0,694	0,671	0,694	0,694	0,671	0,694	0,671	0,694
Equipment Bsim	8,126	**8,126**			0,690	0,623	0,690	0,668	0,690	0,668	0,690	0,690	0,668	0,690	0,668	0,690
People load BE15	1,480	1,406	1,554	0,074	0,126	0,114	0,126	0,122	0,126	0,122	0,126	0,126	0,122	0,126	0,122	0,126
People load Bsim	1,491	**1,491**			0,128	0,114	0,125	0,123	0,127	0,122	0,128	0,125	0,122	0,128	0,122	0,127
Transmission loss BE15	-10,325	-9,808	-10,841	-0,516	-1,278	-1,159	-1,315	-0,880	-0,689	-0,540	-0,373	-0,374	-0,528	-0,804	-1,104	-1,281
Transmission loss Bsim	-16,010	**-16,010**			-0,823	-0,990	-1,417	-1,695	-1,734	-1,628	-1,577	-1,566	-1,531	-1,262	-0,882	-0,905
Ventilation loss BE15	-2,743	-2,606	-2,880	-0,137	-0,410	-0,375	-0,443	-0,249	-0,154	-0,086	-0,005	-0,003	-0,079	-0,194	-0,334	-0,410
Ventilation loss Bsim +	-2,977	**-4,622**			-0,107	-0,127	-0,224	-0,250	-0,345	-0,334	-0,563	-0,503	-0,245	-0,208	-0,119	0,049
Infiltration Bsim	-1,646				-0,100	-0,102	-0,150	-0,161	-0,170	-0,156	-0,156	-0,151	-0,156	-0,140	-0,106	-0,097
Total Ventilation BSim loss	**-4,622**															

Table 22- Comparing the heat balance between BE15 and BSim for validation of the BSim models

Gains from equipment and people loads are within the set 5% allowance. Solar gains, ventilation and transmission loss establish a difference higher than 5% and the reason is explained by the difference in calculation methods documented in section 9.2.

9.5 Implementing the window opening area from 16798-7 in the different options

The implementation of the effective opening areas for Options 1 to 4, is done by using the system option 'Venting' in BSim. This type of system allows the simulation of windows or ventilation openings being opened if the temperature exceeds a user defined set point. The set point for venting used in this paper is 24 °C, as suggested in ISO 13790. When the temperature exceeds the set point the natural ventilation is increased to maintain the desired temperature, up to a user defined maximum air change rate.

The desired natural ventilation model is chosen as 'Single sided' ventilation (One set of openings in one face, in the same vertical level.) from the 'Venting' tab in 'Systems' options. As suggested in the 'Help' instructions in the software the following two values of the parameters are chosen as they will not set a limit and restrict incoming air flow. An air change rate of 10 is given as a maximum in order not to limit the passing air flow. The limit for wind speed is considered in the same aspect. A value of 0 m/s is suggested and set, in order to allow natural ventilation to occur at any wind speed and therefore not affect air flow.

The schedule for the simulations is set to test night ventilation during summer. Time span from June until September is used with hours between 23 and 07 o'clock.

The geometry of windows is considered and entered in the 'WinDoors- Natural ventilation' option. Three parameters are taken into consideration- Discharge coefficient, Effective opening area and Centre of opening area.

The value used for the discharge coefficient Cd is taken as 0.67, as suggested in 16798-7 Calculation Spreadsheet.

The centre of the opening is introduced as the parameter 'Cnt' and takes into consideration the placement of the centre of the window opening area from the lower edge of the window, taking the value as a ratio.

The effective opening window area is taken as a fraction of what can be opened to the total window area. This value is given under the parameter 'Afrac'.

Four types of windows are used, with different opening areas. The opening area sizes are compliant with the areas used in the airflow calculations with the method form 16798-7 for night ventilation and are burglar proof as mentioned in chapter 5. The parameters entered for all four simulations can be seen in section 9.5.

Single sided Simulations 10

The current chapter documents the effects from the implementation of different parameters, used by the calculation method in 16798-7, and the dynamic simulation of the case study in BSim. Due to BSim's ability to simulate and express changes in the environment on an hourly basis, the outcome from the program is considered as 'true' value. The product of the 16798-7 calculation method is compared to BSim results and further analysed.

Detailed description of the simulation parameters in respect to boundary conditions and temperature set up is provided in the following tables. The conditions concerning window types and effective opening areas are used throughout the whole simulation process.

10.1 Simulation set up Single Sided ventilation

As previously introduced simulations regarding natural ventilation are executed on a thermal zone level in the dynamic software tool. A total of 4 simulations are done, one per each type of window opening. The following tables show the inputs considered and entered for options 1 to 4 in BSim. The opening area for each of the options as described in chapter Window Study is adjusted to the window size in Bsim, in compliance with its calculation and simulation method.

Window type	Window area (m2)	Window opening area (m2)	Afrac-Ratio of opening to window area (-)	Cnt- Centre of opening area height (-)	Cd- Discharge coefficient (-)	Zone placement
W1 to W1.4	1.8	0.29	0.16	0.92	0.67	Zone 1 to 4
W2	6.6	0.29	0.044	0.98	0.67	Zone 5
W3	5.25	0.29	0.055	0.967	0.67	Zone 7
W4	8.8	0.29	0.033	0.98	0.67	Zone 8
W5	7	0.29	0.041	0.98	0.67	Zone 8

Table 23-parameters entered in BSim under the venting schedule for Option 1

Window type	Window area (m2)	Window opening area (m2)	Afrac-Ratio of opening to window area (-)	Cnt- Centre of opening area height (-)	Cd- Discharge coefficient (-)	Zone placement
W1 to W1.4	1.8	0.029	0.016	0.99	0.67	Zone 1 to 4
W2	6.6	0.029	0.0044	0.997	0.67	Zone 5
W3	5.25	0.029	0.0055	0.997	0.67	Zone 7
W4	8.8	0.029	0.0033	0.998	0.67	Zone 8
W5	7	0.029	0.0041	0.997	0.67	Zone 8

Table 24-parameters entered in BSim under the venting schedule for Option 2

Window type	Window area (m2)	Window opening area (m2)	Afrac-Ratio of opening to window area (-)	Cnt- Centre of opening area height (-)	Cd- Discharge coefficient (-)	Zone placement
W1 to W1.4	1.8	0.0145	0.0081	0.004	0.67	Zone 1 to 4
W2	6.6	0.0145	0.0022	0.0011	0.67	Zone 5
W3	5.25	0.0145	0.0028	0.002	0.67	Zone 7
W4	8.8	0.0145	0.0016	0.001	0.67	Zone 8
W5	7	0.0145	0.002	0.001	0.67	Zone 8

Table 25- parameters entered in BSim under the venting schedule for Option 3

Window type	Window area (m2)	Window opening area (m2)	Afrac-Ratio of opening to window area (-)	Cnt- Centre of opening area height (-)	Cd- Discharge coefficient (-)	Zone placement
W1 to W1.4	1.8	0.1566	0.087	0.956	0.67	Zone 1 to 4
W2	6.6	0.1566	0.024	0.988	0.67	Zone 5
W3	5.25	0.1566	0.0298	0.98	0.67	Zone 7
W4	8.8	0.1566	0.018	0.99	0.67	Zone 8
W5	7	0.1566	0.022	0.988	0.67	Zone 8

Table 26-parameters entered in BSim under the venting schedule for Option 4

Applying the effective opening area stated in options 1 to 4, a total of 704 simulations for single sided ventilation are done, using the calculation method from 16798-7. The simulations are done on a zone level as suggested in the pre standard. Due to window placement, 2 zones are simulated. A zone with one window and a zone with two windows, because they represent the change in air flow for the building. 16798-7 air flow is calculated based on the total window opening area. Zone 1, representing the amount of flow for 6 zones and Zone 8 for itself. Simulated flow for zones 1 to 8 are added together in order to represent the flow on a building level. This simplifies the comparison between the two software programs. Three sets of parameters were changed and combined in order to establish a realistic representation of the conditions and extract an air flow representing those conditions. The change in parameters covers internal and external temperatures, and topography and roughness coefficients. The topography and roughness coefficients are used as wind speed correction factors, calculated from ISO 15927-1. They are referred to as 'Calculated coefficients'. Default values given in 16798-7, Annex B-section B.3.4.2 wind speed correction factors, are referred to as 'Default coefficients'. A step wise approach is done leading the progression of simulations in the following order:

Simulation number:	Parameters combination:	Further referred to as:
Simulation 1.a	-Internal Design temperature for night cooling from ISO13790, 24°C -Monthly mean external temperature -Calculated coefficients as recommended	DZT+MAET+CC
Simulation 1.b	-Internal Design temperature for night cooling from ISO13790, 24°C - Monthly mean external temperature - Default coefficients as recommended	DZT+MAET+DC

Simulation 1.c	-Internal Design temperature for night cooling from ISO13790, 24°C - Monthly mean night external temperature -Calculated coefficients as recommended	DZT+NAET+CC
Simulation 1.d	-Internal Design temperature for night cooling from ISO13790, 24°C -Monthly mean night external temperature -Default coefficients as recommended	DZT+NAET+DC
Simulation 2.a	-Maximum Internal Design temperature from the Danish building regulations 28°C - Monthly mean external temperature -Default coefficients as recommended	ULT+MAET+DC
Simulation 2.b	-Maximum Internal Design temperature from the Danish building regulations 28°C -Monthly mean night external temperature -Default coefficients as recommended	ULT+NAET+DC
Simulation 3.a	-Iteration using internal temperature from the BE15 model - Monthly mean external temperature -Default coefficients as recommended	BE15RT+MAET+DC
Simulation 3.b	-Iteration using internal temperature from the BE15 model -Monthly mean night external temperature -Default coefficients as recommended	BE15RT+NAET+DC

Table 27- Simulation steps

10.2 Simulation Results:

The following figures show the simulated air flow values throughout the steps stated in table 27, calculated in 16798-7, compared to BSim air flow.

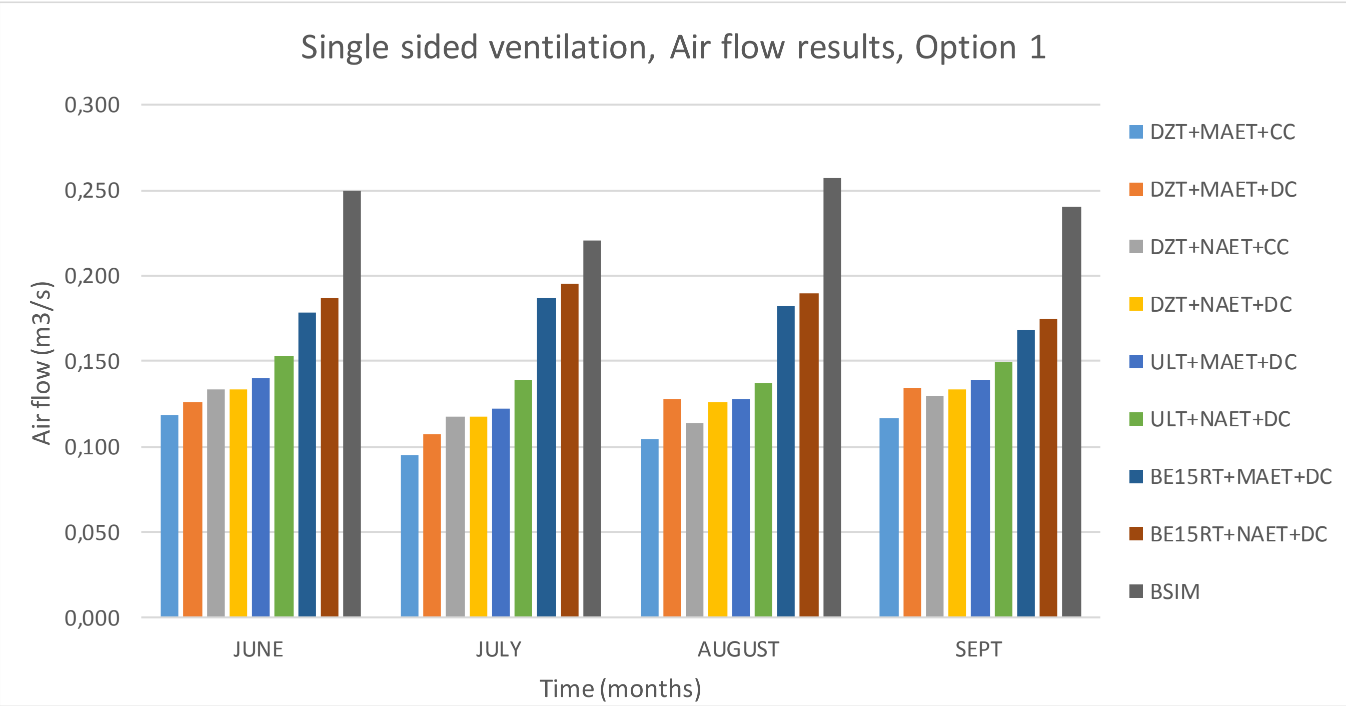

Figure 10- Single sided ventilation, Air flow results, Option 1

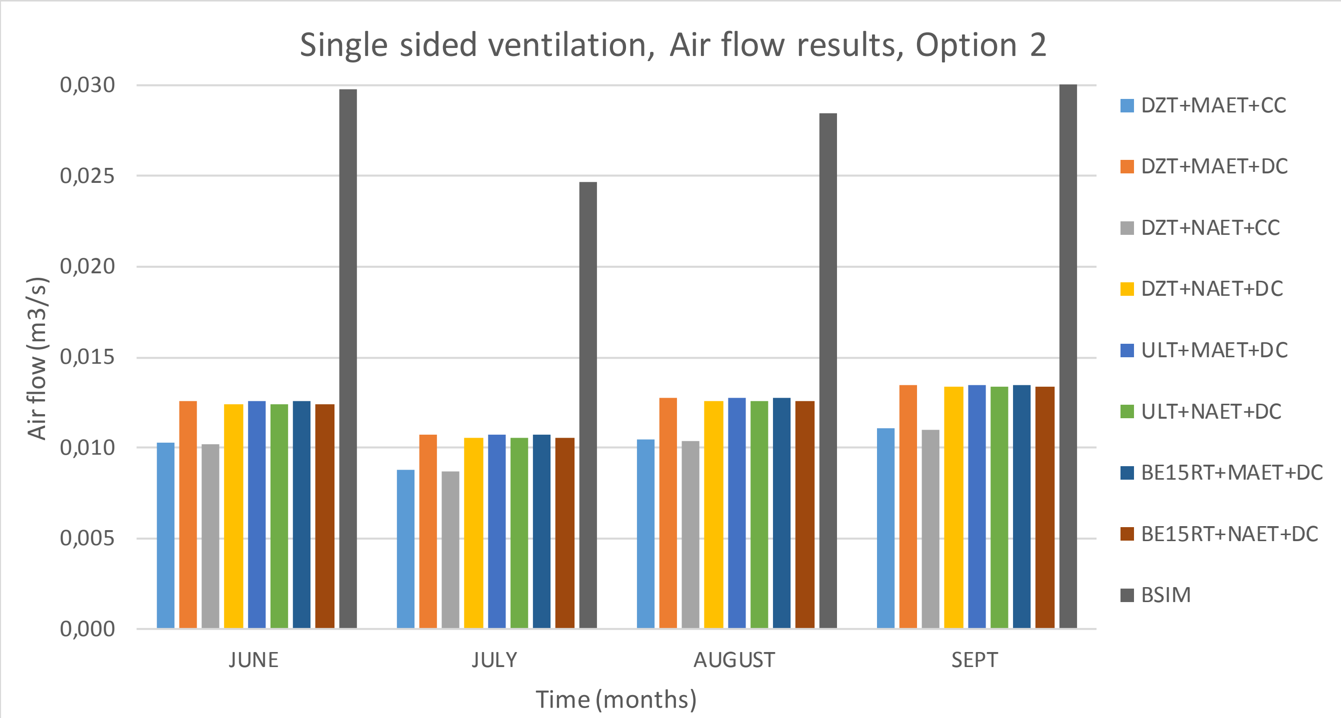

Figure 11-Single sided ventilation, Air flow results, Option 2

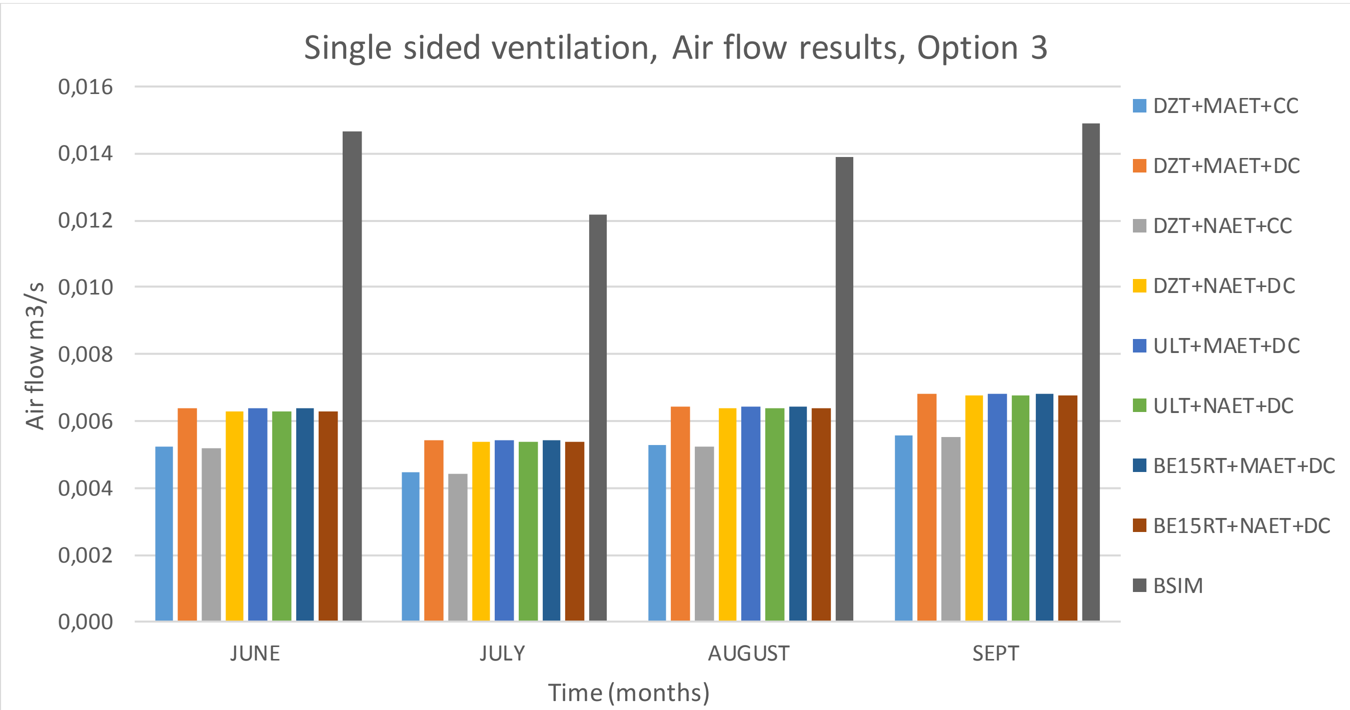

Figure 12-Single sided ventilation, Air flow results, Option 3

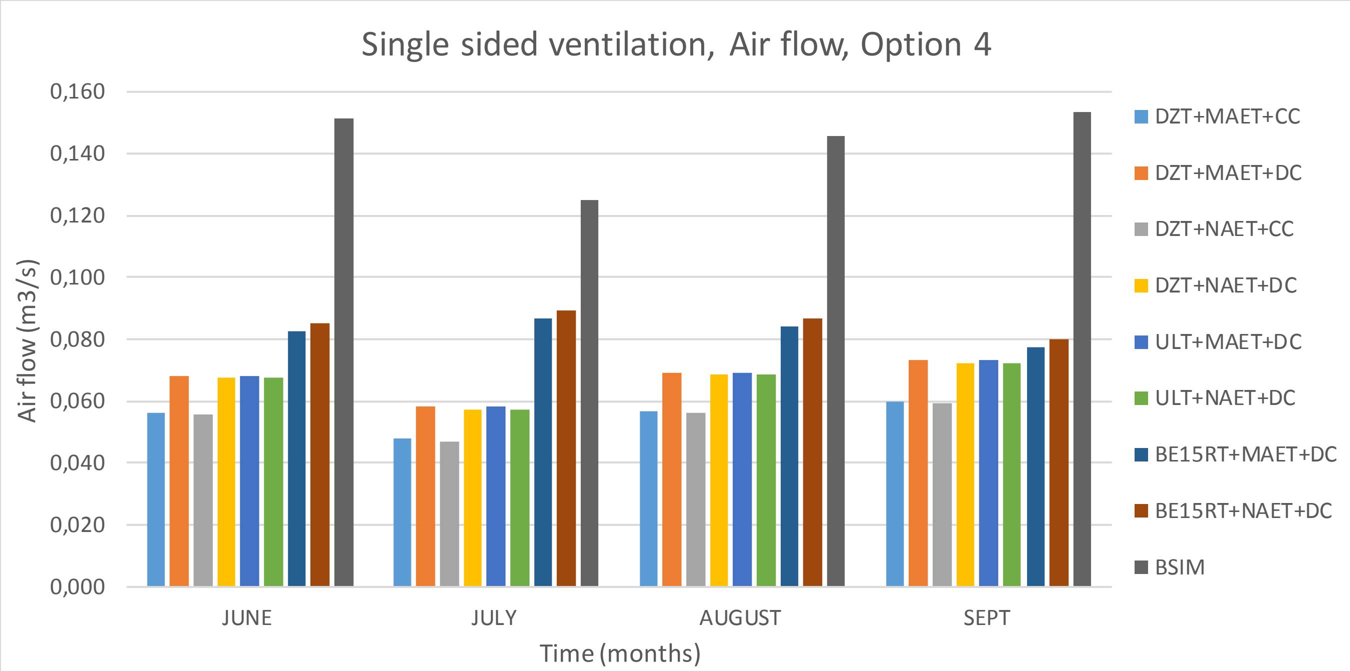

Figure 13- Single sided ventilation, Air flow results, Option 4

On the following figure the change in room temperature between BE15and BSim can be seen according to each Option applied.

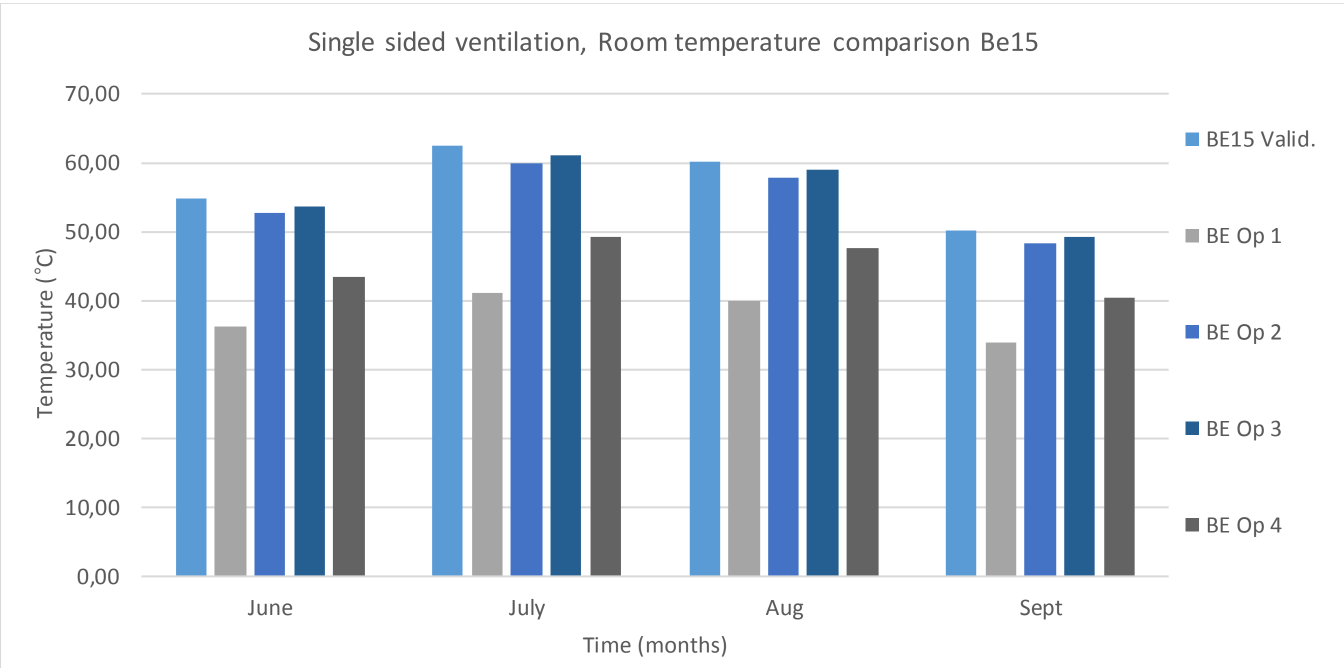

Figure 14-Single Sided Ventilation room temperatures from the BE15 comparing the 4 window options

Both BE15 and BSim simulations follow the same tendency. The largest temperature drop is seen in Option 1, followed by Option 4, 2 and 3. The order in which the values are placed follows the windows ability to open, meaning the larger the effective opening area, the larger the flow provided and higher temperature drop noticed.

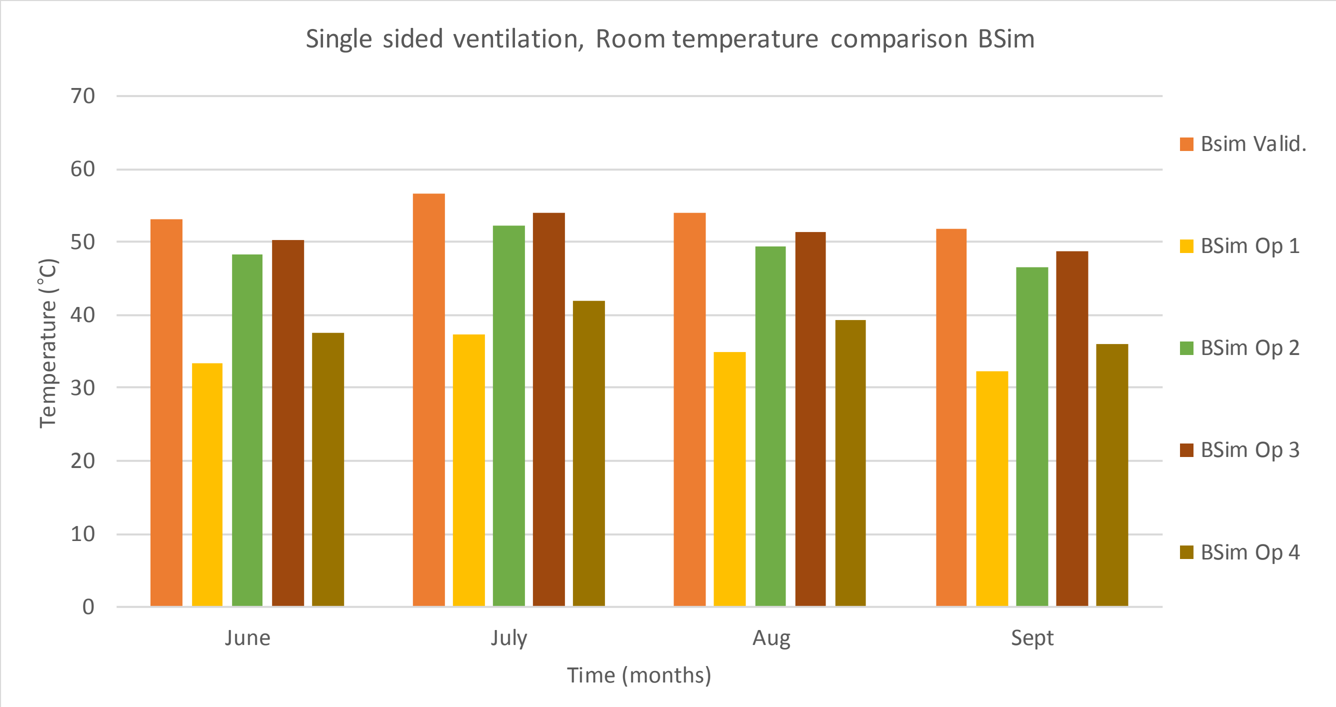

Figure 15-Single Sided Ventilation room temperatures from BSim comparing the 4 window options

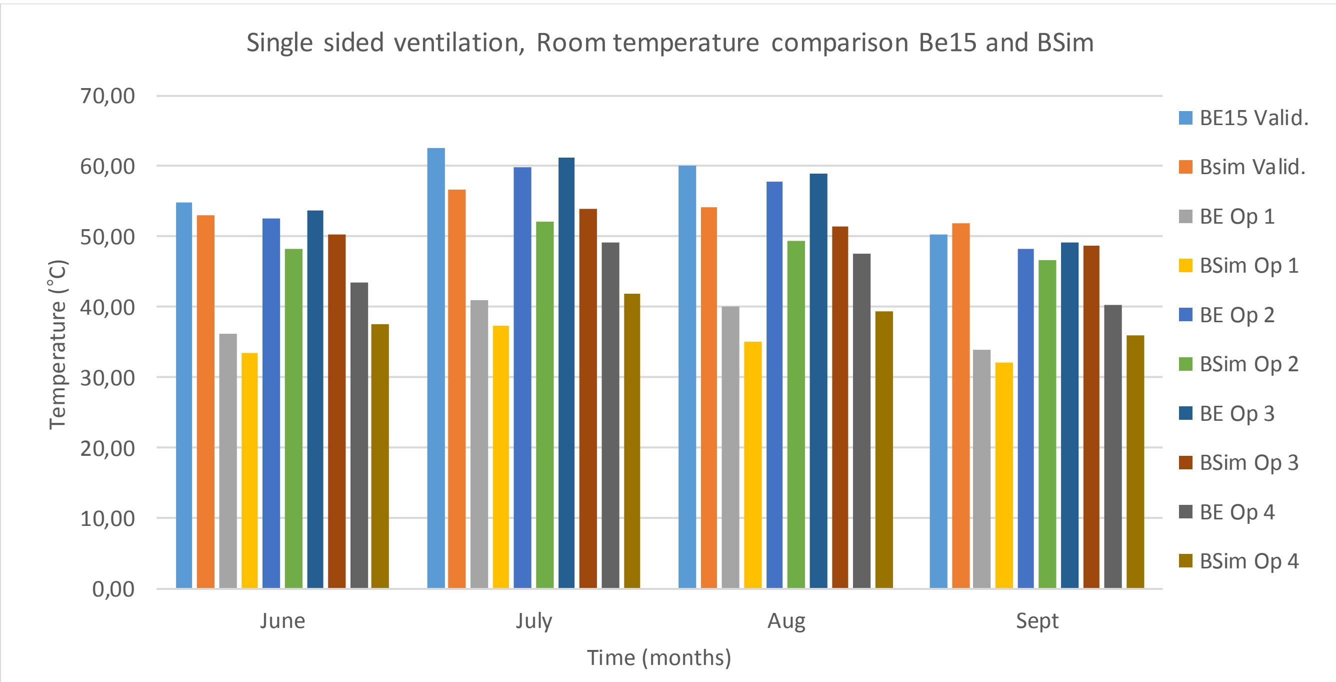

Figure 16-Single Sided Ventilation room temperatures from the BE15 and BSim comparing the 4 window options

10.3 Simulation analysis:

A starting point of the 16798-7 simulations was the combination of internal design temperature for night cooling of 24°C, monthly average external temperature, currently provided in the weather file in BE15 and calculated coefficients as suggested in 16798-7. By reason of investigating night ventilation a comparison of monthly mean external temperature and monthly mean night external temperature is done. Furthermore, due to the calculation method for this natural ventilation principle, change in internal and external temperature directly affects the air flow.

The air flow derived from the dynamic software tool is larger compared to the 16798-7 flow in all variations of ventilation zone temperature, external temperature and coefficients simulated. This can be described by the fact BSim air flow calculation procedure takes airflow as a result of the combined effect of wind and thermal buoyancy, compared to 16798-7. As documented in chapter 7, the airflow in 16798-7 is calculated either as wind or temperature driven. Therefore, further investigation is done to determine the dominant force in the air flow calculations.

As described in chapter 7, the following formula is used in the airflow calculation procedure in 16798-7.

Equation 10

$$q_{V;arg;in} = 3600 \times \frac{\rho_{a;ref}}{\rho_{a;e}} \cdot \frac{A_{w;tot}}{2} \cdot \boxed{\max\left(C_{wind} \cdot u_{10;site}^{2} ; C_{st} \cdot h_{w;st} \cdot abs\left(T_z - T_e\right)\right)^{0,5}}$$

The equation states, the maximum value of the two mathematical expressions in the brackets is taken and used for the further calculation of the flow. The two forces are calculated separately and compared to one another in order to determine the driving force. Due to the fact there are two sets of coefficients used in this paper, an adjustment of wind speed is made to obtain the proper value regarding the equation. In the table below a manual calculation of the wind speeds depending on month and coefficients used for the formula can be seen.

Calculation of U10;site	**June**		**July**		**August**		**September**	
	Calculated	**Default**	**Calculated**	**Default**	**Calculated**	**Default**	**Calculated**	**Default**
Crgh;10;site	0,77	0,8	0,77	0,8	0,77	0,8	0,77	0,8
Ctop;10;site	1	1	1	1	1	1	1	1
Crgh;met	1,17	1	1,17	1	1,17	1	1,17	1
Ctop;met	1	1	1	1	1	1	1	1
U10 (monthly average DRY2013) (m/s)	4,4		3,7		4,4		4,7	
U10;site (m/s)	**2,90**	**3,52**	**2,44**	**2,96**	**2,90**	**3,52**	**3,09**	**3,76**

Table 28-calculation of the U10:site

The following table contains the results of the calculation regarding determination of driving force. The higher value is marked in red. It indicates how the driving force changes depending on the values of the variable parameters used in the calculation. It displays dominant thermal buoyancy when calculated coefficients are used, due to the fact they take 66% of the meteorological wind speed at 10 meter height compared to the default coefficients that take 80% of the value.

The difference between calculated and default coefficients is used only in the simulation with design zone temperature at 24 °C. For further simulations only default coefficients are used.

OPTON 1	JUNE	JULY	AUGUST	SEPT
Design zone temp + MAET+CC				
Wind speed (m/s)	2,90	2,44	2,90	3,09
calculation	0,0917	0,0772	0,0917	0,0977
Temperature difference (ΔT)	9,77	6,22	6,12	9,46
calculation	0,1046	0,0835	0,0828	0,1029
Design zone temp + MAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	9,77	6,22	6,12	9,46
calculation	0,1046	0,0835	0,0828	0,1029

Table 29-calculation of driving force for Option 1

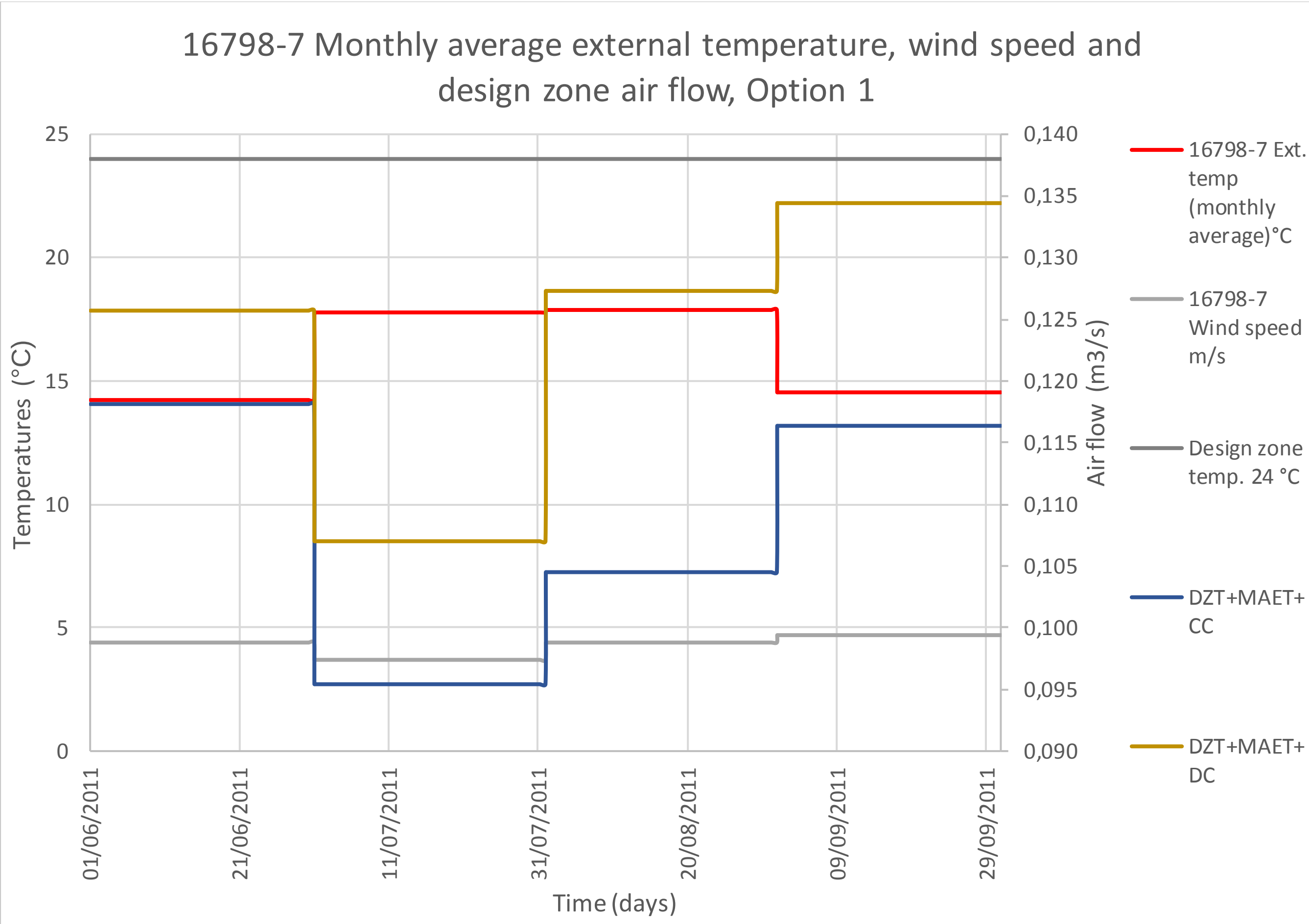

Figure 17-16798-7 Monthly average external temperature, wind speed and design zone air flow, Option 1

The graphical representation of the 16798-7 air flow with design zone temperature and monthly mean external temperature presents the changes in flow depending on the change in driving force. Flow calculated with calculated coefficient is driven by thermal buoyancy during the period of June, July and September and by wind prevailing in August. When external temperature increases during July, air flow diminishes due to the temperature difference between ventilation zone and external temperature getting smaller. During August wind speed increases and flow increases, because the driving force changes. In September flow grows when external temperature decreases and the temperature difference increases.

A simulation with different external temperature is done, because of the paper's interest in night ventilation. Using the DRY 2013 weather data, external temperature during the night period from 23 to 07 o'clock is taken out and an average for this period during the month is made. It Is referred to as Monthly mean night external temperature.

The following graph represents the same conditions as in figure 17 with a change in external temperature. The external temperature during night is lower, resulting in lower monthly mean values. This leads to higher temperature differences.

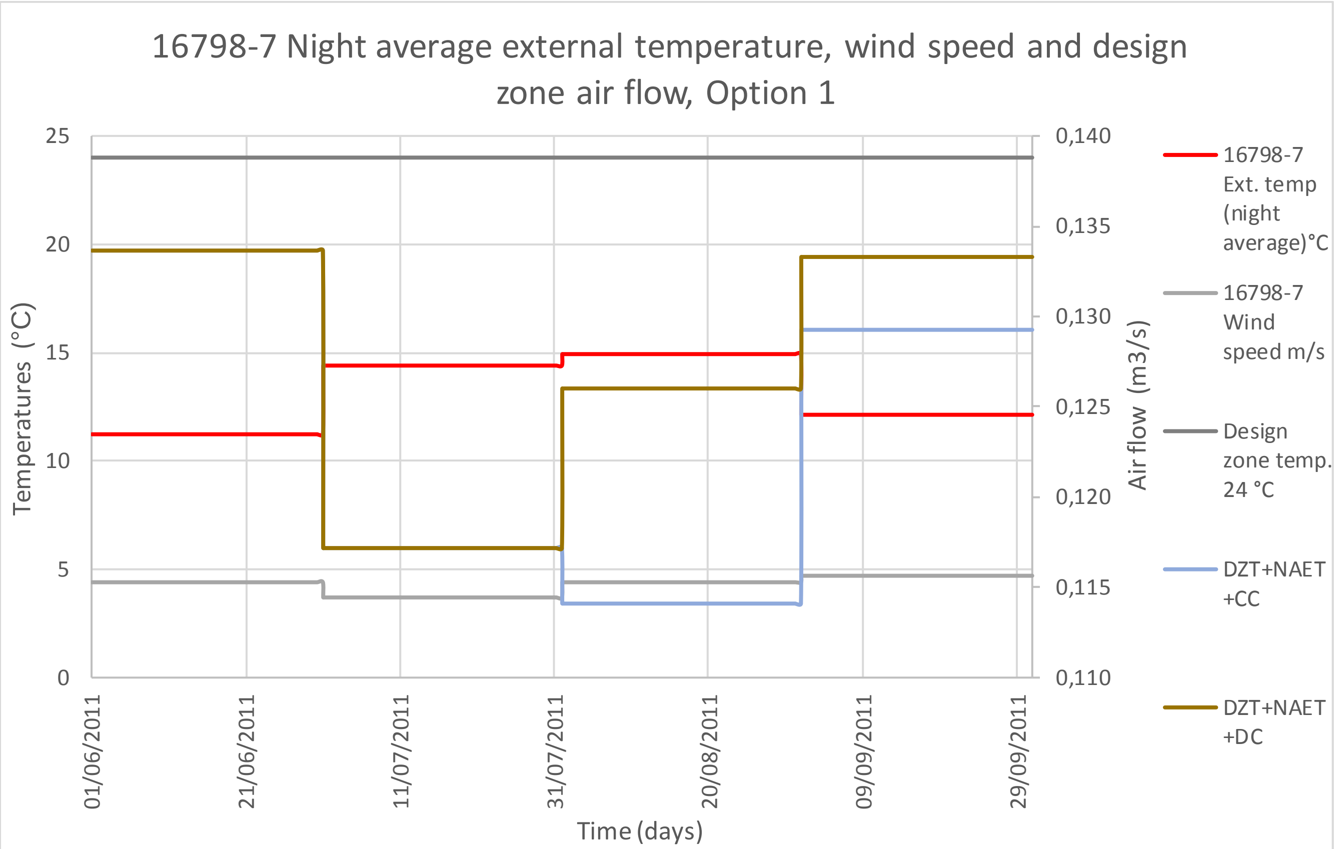

Figure 18-16798-7 Night average external temperature, wind speed and design zone air flow, Option 1

OPTON 1	JUNE	JULY	AUGUST	SEPT
Design zone temp + NAET+CC				
Wind speed (m/s)	2,90	2,44	2,90	3,09
calculation	0,0917	0,0772	0,0917	0,0977
Temperature difference (ΔT)	12,77	9,60	9,07	11,87
calculation	0,1196	0,1037	0,1008	0,1153
Design zone temp + NAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	12,77	9,60	9,07	11,87
calculation	0,1196	0,1037	0,1008	0,1153

Table 30-Calculated driving forces for option 1

Table 30, indicates how dominating force shifts with the increase of temperature difference.

The diagram on top displays the changes in air flow amount and the affecting parameters. In both cases, with default and calculated coefficients, the flow is controlled by buoyancy during June and July. During August and September the flow calculated with default terrain coefficients shifts force to wind and is represented on the graph by increase of air flow when wind speed increases. Air flow calculated using calculated coefficients is fully buoyancy dependent. When temperature difference decreases, flow decrease.

Due to the fact Building Regulations 2015 section 6.2 (1) set a limit on overheating hours in residential buildings, in which windows can be opened and used for natural ventilation, a simulation with different zone temperature is done. The zone temperature is set at 28 °C and simulated with two different external temperatures and only default coefficients.

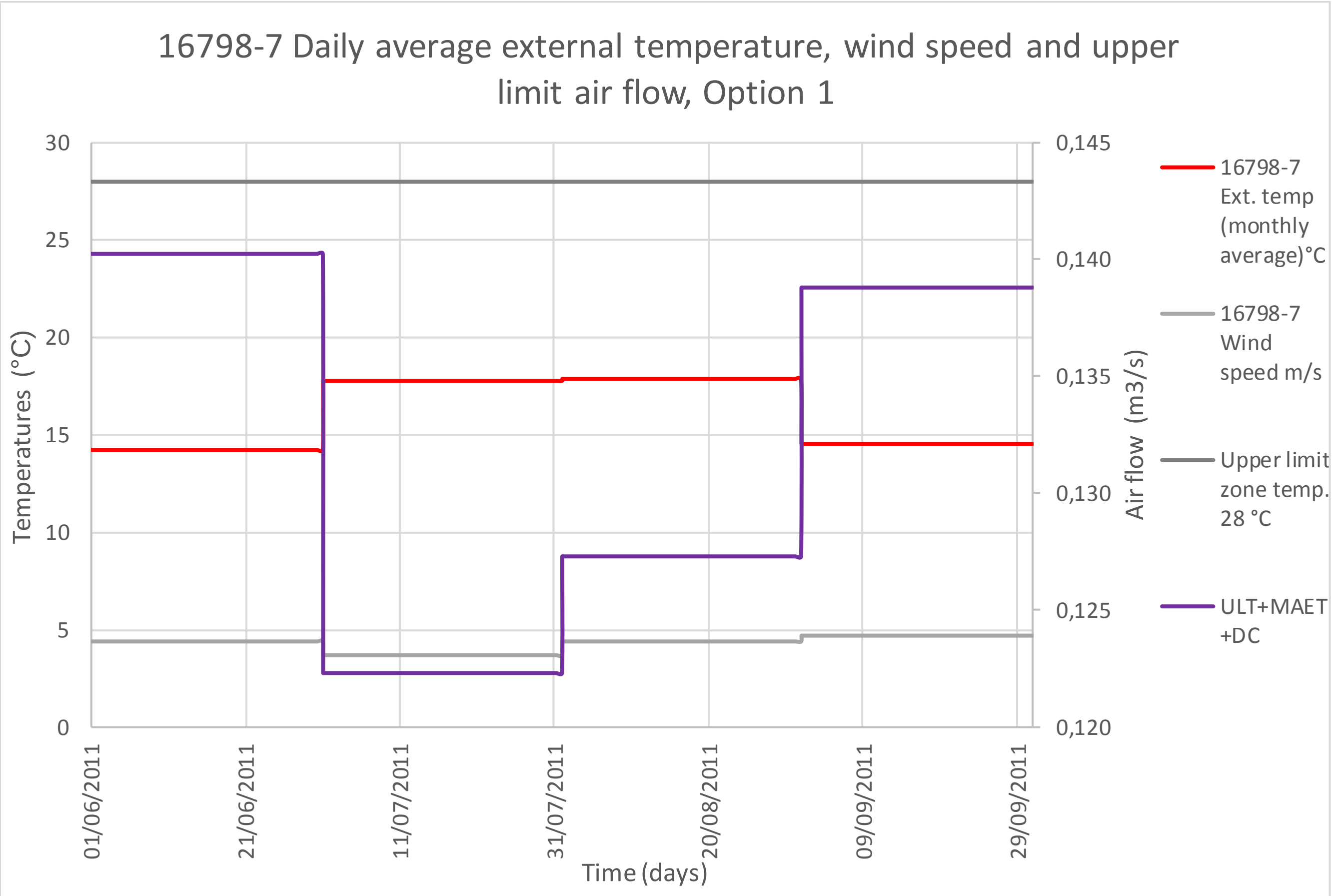

Figure 19-16798-7 Daily average external temperature, wind speed and upper limit air flow, Option 1

From the table below it can be seen thermal buoyancy is dominant 75% of the period and rest 25% are overtaken by wind, which explains the rise in air flow during the period of August.

As a tendency in the calculations with default coefficients can be noticed that with the increase in temperature difference between the ventilation zone and outside, wind relinquishes its' position as dominant force to thermal buoyancy.

OPTON 1	JUNE	JULY	AUGUST	SEPT
Upper limit temp+ MAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	13,77	10,22	10,12	13,46
calculation	0,1242	0,1070	0,1065	0,1228
Upper limit temp+ NAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	16,77	13,60	13,07	15,87
calculation	0,1370	0,1234	0,1210	0,1333

Table 31- calculation of driving forces with the upper limit 28°C

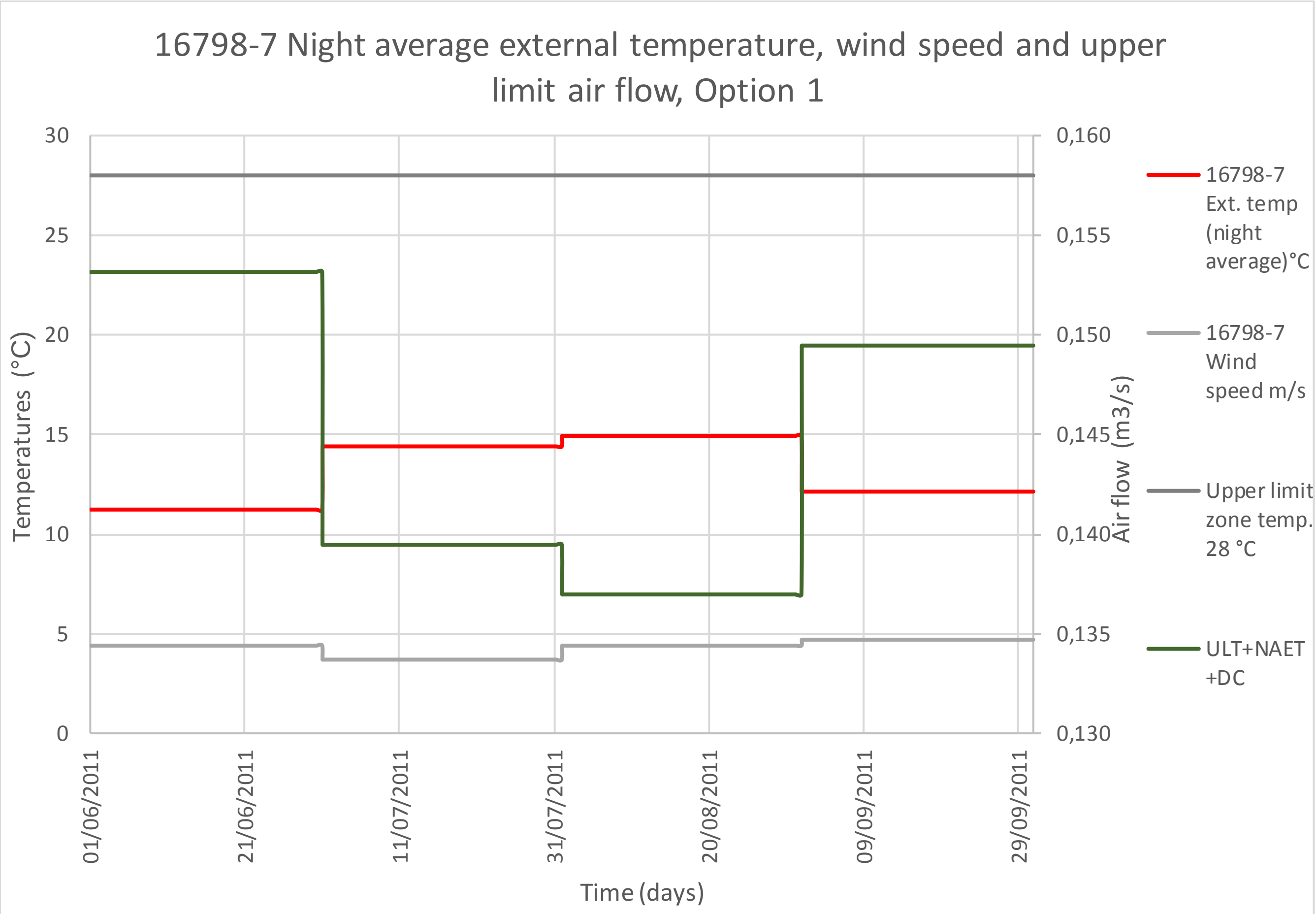

Figure 20-16798-7 Night average external temperature, wind speed and upper limit air flow, Option 1

Because of BSim's calculation method and that it uses internal room temperature in the air flow calculation, a simulation with room temperatures for the ventilation zone in 16798-7 is done as well. An iteration method is used in order to find stable air flow based on ventilation zone temperatures calculated in BE15 excel sheet. On the table below can be seen the change of temperature differences in comparison with the previous simulations.

The table displays dominant thermal buoyancy force in both tested cases. A graphical representation of the flow and how it changes depending on temperature difference can be seen in figures 21 and 22.

OPTON 1	JUNE	JULY	AUGUST	SEPT
BE15 room temp+ MAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	22,37	23,72	22,62	19,76
calculation	0,1583	0,1630	0,1592	0,1488
BE15 room temp+ NAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,1113	0,0936	0,1113	0,1189
Temperature difference (ΔT)	24,97	26,70	25,07	21,77
calculation	0,1672	0,1729	0,1676	0,1561

Table 32-calculation of driving forces with internal BE15 room temperatures for Option 1

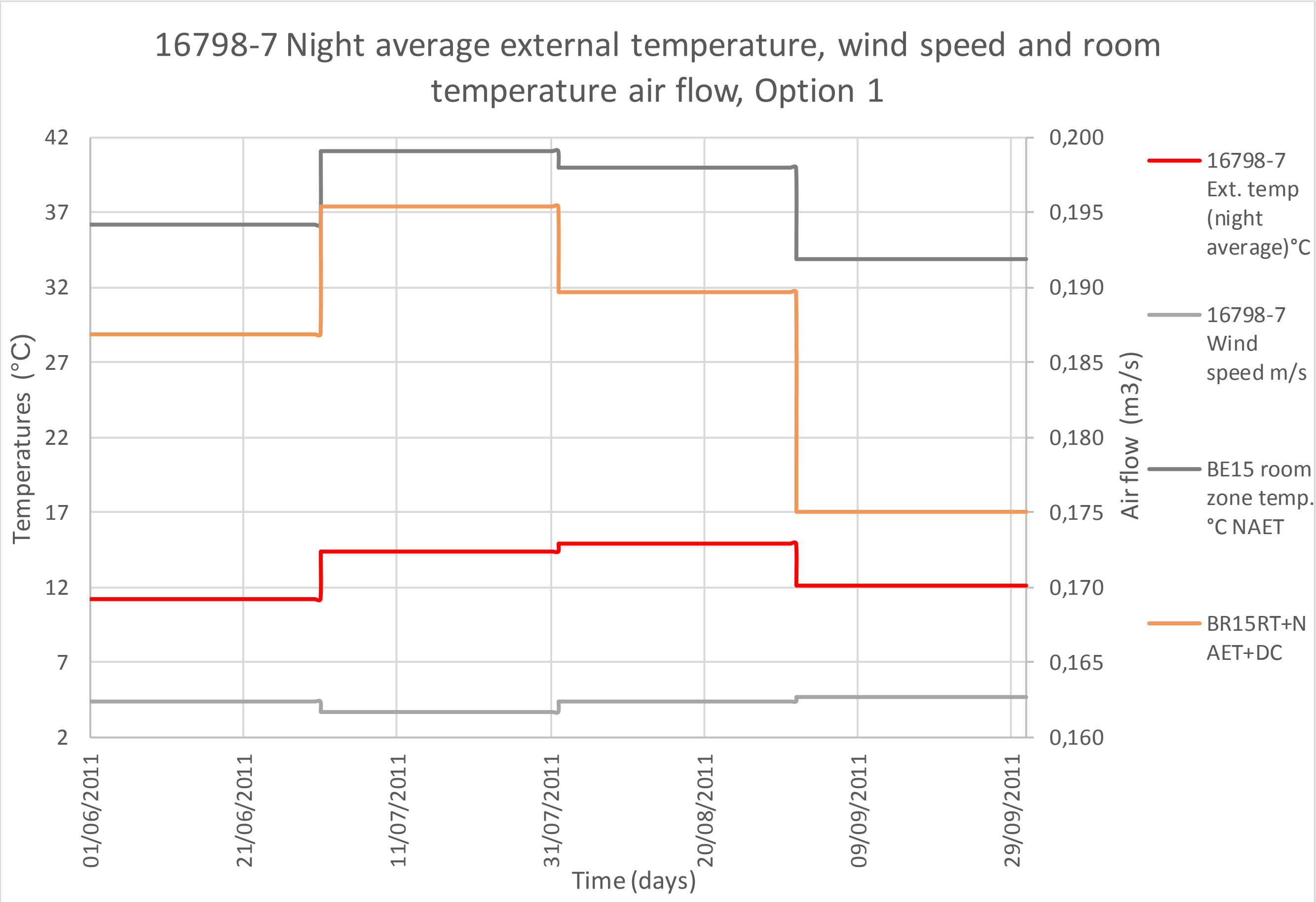

Figure 21-16798-7 Night average external temperature, wind speed and room temperature air flow, Option 1

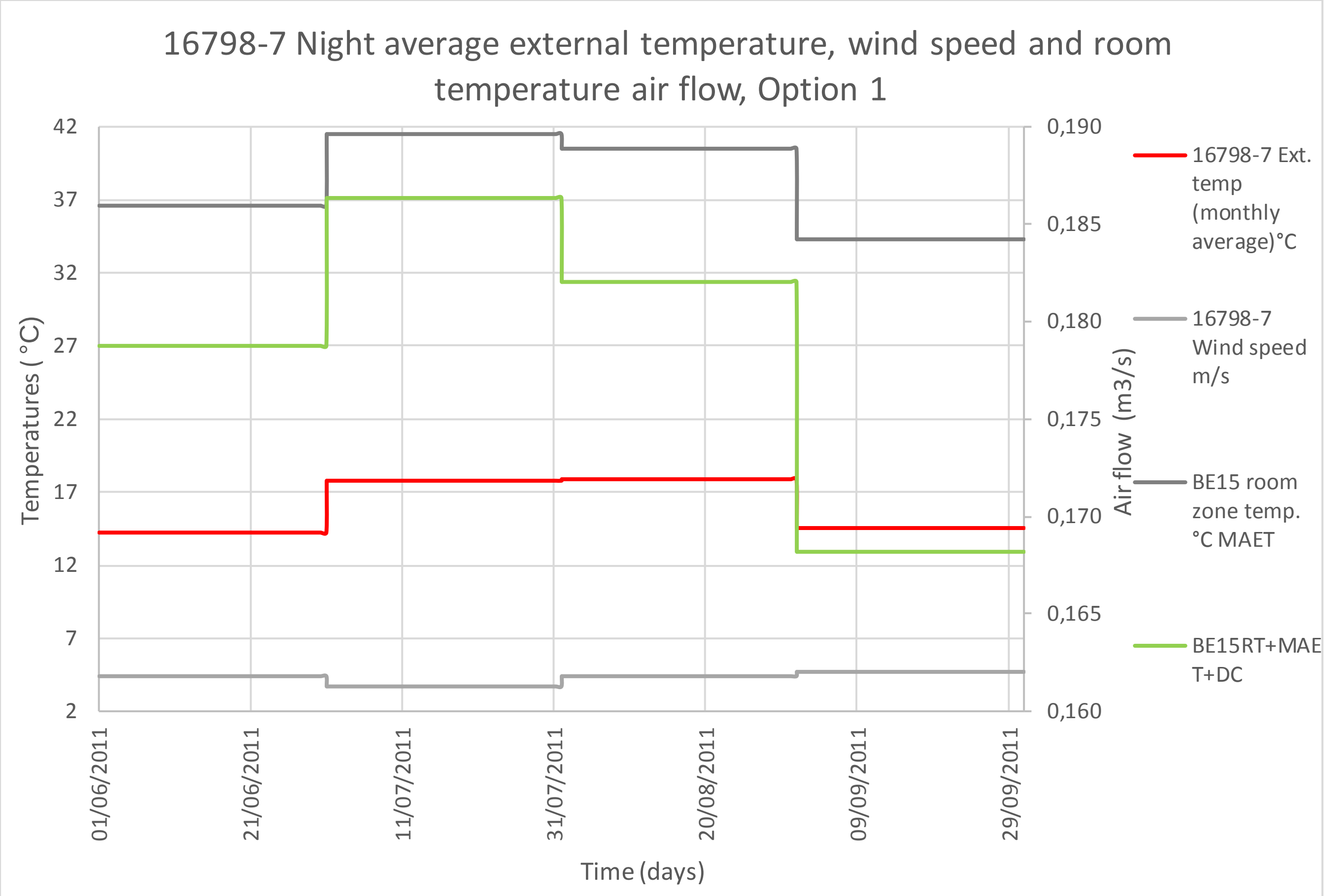

Figure 22-16798-7 Night average external temperature, wind speed and room temperature air flow, Option 1

Both diagrams follow the same tendency and display a rise in room and external temperature during July. The increase of room temperature is larger than the increase of external temperature. This difference results in rise of temperature difference, which consequently affects the air flow in a positive way, increasing it. During August the rise in external temperature and decrease in room temperature leads to decrease in air flow. In September room and external temperature decrease, one more than the other, leading to a decrease in temperature difference and air flow accordingly.

With rise in temperature difference, a shift in airflow driving force is observed. Using the proper external and ventilation zone temperatures are decisive for the calculation. Throughout the simulation procedure a tendency of underestimating in flow is noted for the 16798-7 method in comparison to BSim values.

10.4 Simulation analysis compared to SBi 213 airflow value suggestion

As calculated in section 6.1, airflow suggested in SBi 213 for night ventilation with manually operated windows is as follows:

Air flow for night ventilation calculated on a building level is 0.055 m3/s.

The following figures demonstrate the difference between calculated airflow and values suggested in the SBi 213 for Single sided ventilation.

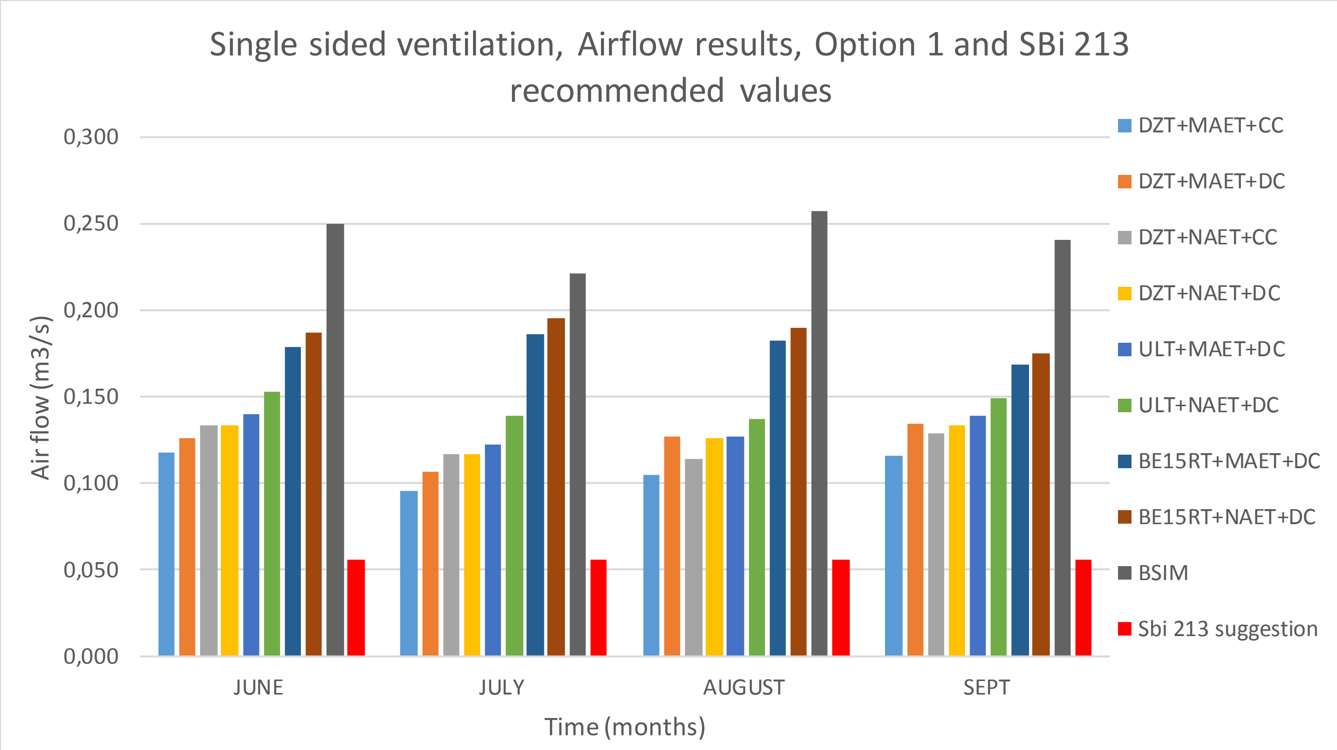

Figure 23-Single sided ventilation, Airflow results, Option 1 and SBi 213 recommended values

The air flow marked in red represents the SBi 213 recommended value. The effective opening area of the windows in Option 1, calculated according to the SBi's recommended percentages, covers the minimum for the current natural ventilation principle used. The suggested value is around 2 to 3.4 times lower in comparison with the calculated air flow. It was established the calculation method in 16798-7 underestimates the flow for single sided ventilation and additionally SBi 213 underestimates it further.

Options 2 and 3 do not cover the criteria for necessary effective opening area of the windows and recommended SBi values overestimate the flow with around 5 and 11 times respectively. Option 4 does not have the necessary effective opening area as well, but in this case the flow is overestimated up to 1.5 times. Graphical representation of the results can be seen in Appendix G.2

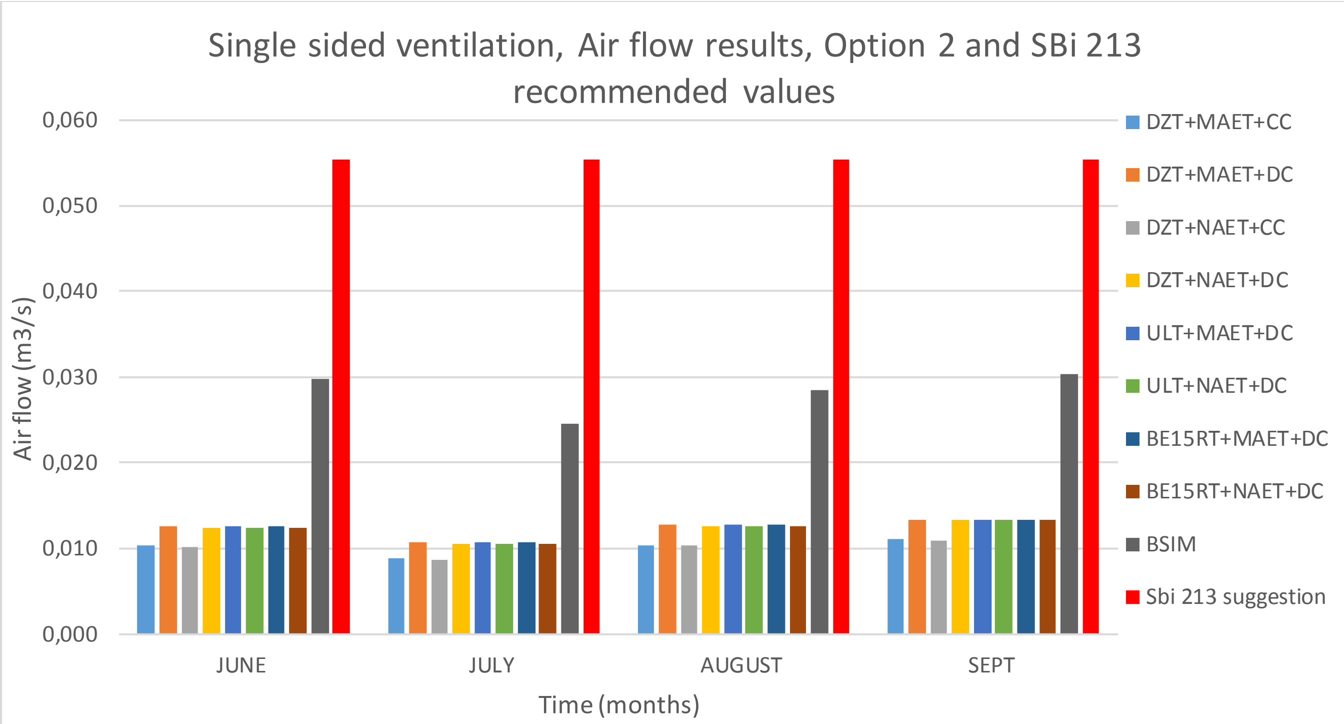

Figure 24-Single sided ventilation, Air flow results, Option 2 and SBi 213 recommended values

Cross Ventilation Simulations 11

11.1 Simulation set up Cross

Simulation of Cross ventilation in BSim was done based on the same parameters used in chapter 10 (single sided ventilation). The effective opening area of windows, discharge coefficient and placement is kept the same for the 4 options used. The type of natural ventilation is chosen in the 'Venting' tab as 'Cross' ventilation. Compared to Single sided ventilation an additional input is needed to be able to simulate this type of ventilation- the implementation of a wind pressure coefficient – Cp. The coefficients are implemented in the simulation software and cannot be chosen by the user. They are chosen in the 'Façade finish property' for the external façade of the openings. The tab 'Wind exposure' gives three opportunities to select from. Based on the terrain and placement of the building in comparison to surrounding buildings, 'Semi-exposed' type is appointed. Wind pressure coefficients are based on the building model as previously mentioned. Therefore assuming the model is correct, the applied values should be for square floor plan ratio 1:1, for low rise buildings, surrounded by obstructions, equivalent to half of the building height. Wind pressure coefficients are provided by SBi 202, and can be seen in Appendix A.

11.2 Simulation results

The following tables shows the change in losses depending on the performed simulation in BSim.

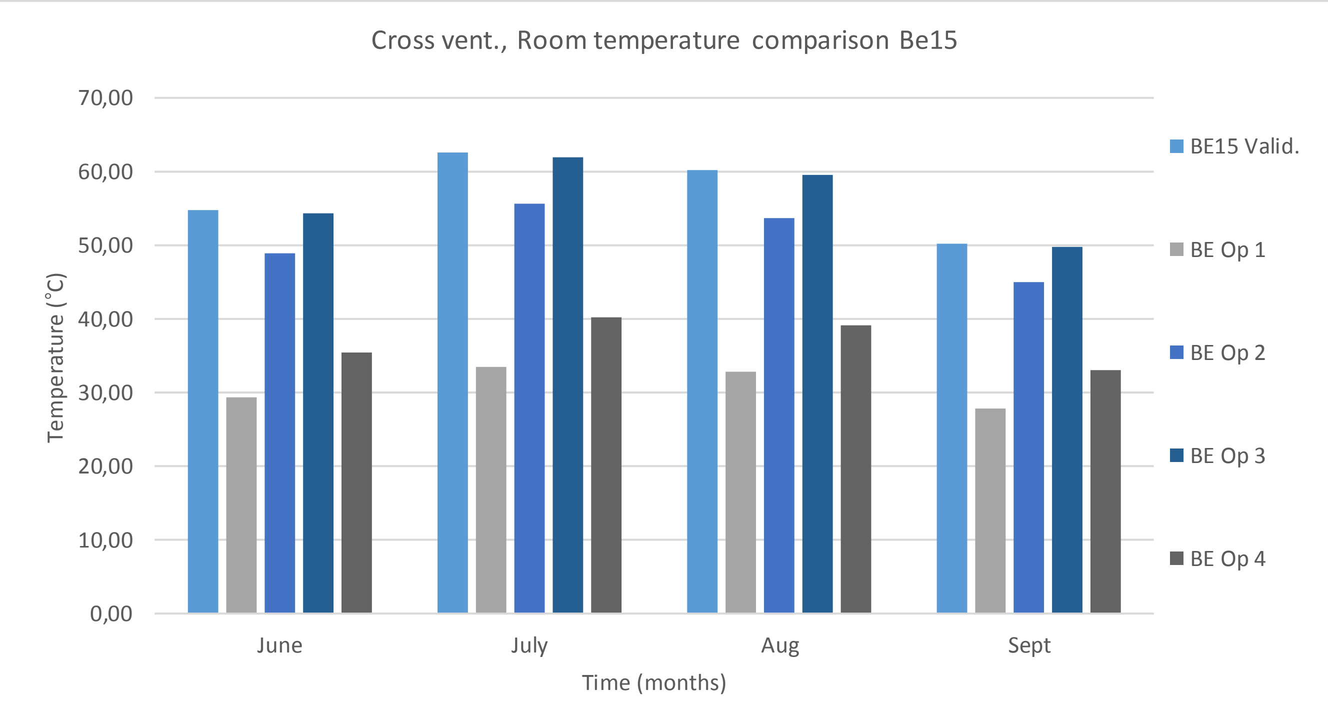

Figure 25-Cross vent., Room temperature comparison Be15

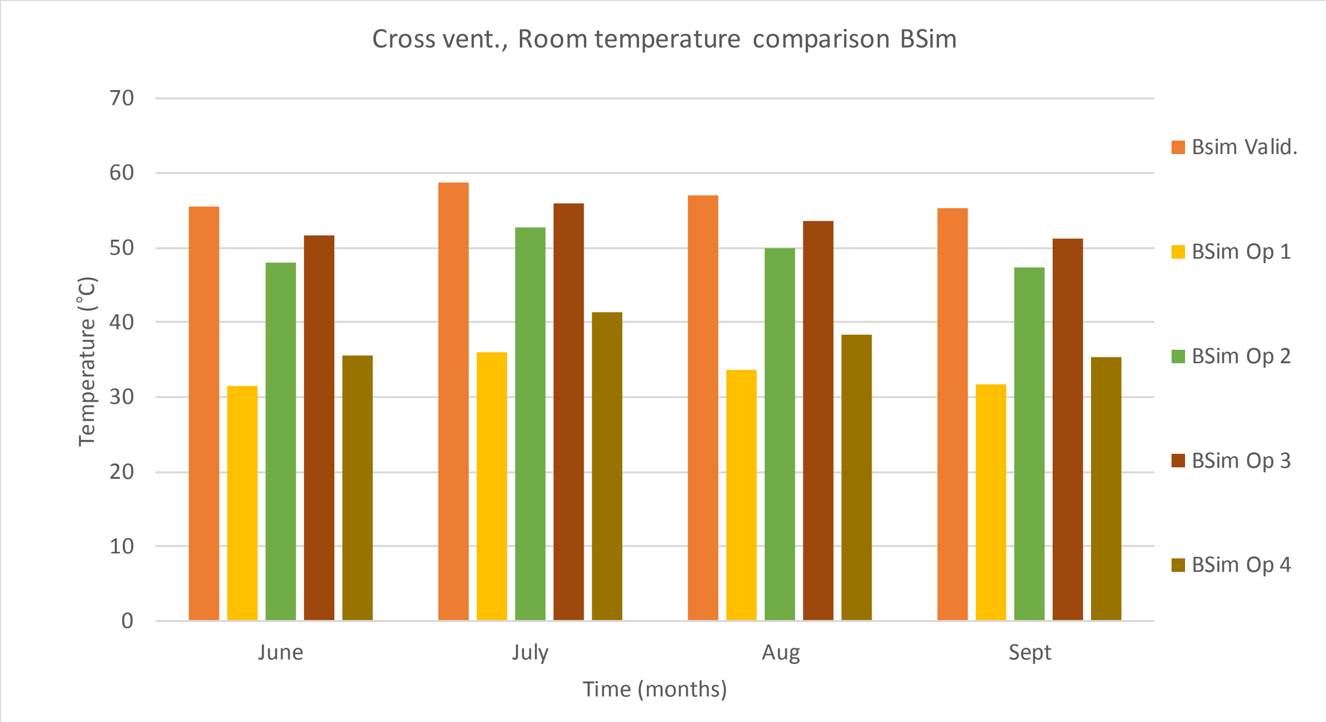

Figure 26-Cross vent., Room temperature comparison BSim

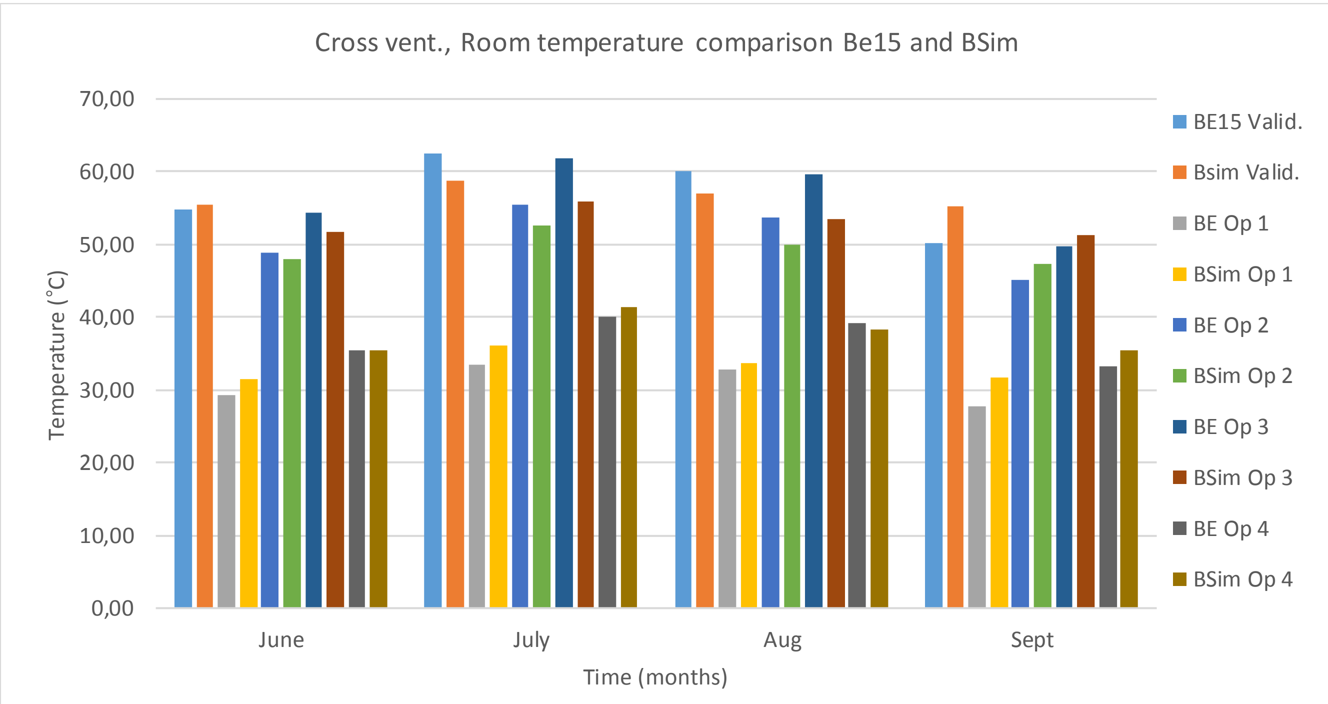

Figure 27-Cross vent., Room temperature comparison Be15 and BSim

The room temperatures follow the same tendencies as in Single sided ventilation, with the difference that provided air flow is larger for cross ventilation.

11.3 Sim analysis

The following figures below show the calculated airflows from the different options during the period from June to September.

The method calculation of air flow is based on the same principles as Single sided ventilation. The 16798-7 calculates the flow based on one ventilation zone and Bsim takes into consideration different thermal zones. In order to have a proper simulation of cross ventilation regarding flow path, the dynamic model is rearranged to a single zone model.

The simulation process follows the same steps as in Chapter Single sided ventilation. Deeper investigation is needed for this natural ventilation principle. Compared to single sided ventilation simulations, more parameters are changed throughout the process. The simulations with same parameters in both ventilation principles connected to temperatures and coefficients have the same title. The additions to Simulations 1 to 4 are referred to as 'Attempts' in the paper. There are 3 Attempts performed, based on difference in wind pressure coefficients used and wind speed.

Attempt 1 is a simulation done for each window Option 1 to 4, using a difference in wind pressure coefficients of $\Delta Cp=0.45$. As previously stated 16798-7 suggests two ways of calculating the wind pressure coefficients. Both of them were tested and the results in air flow are overestimated, because the direct effect the coefficient has on the flow. The larger the value, the larger the flow. By reason of this, it is chosen to simulate with coefficients related to the ones in BSim. Detailed calculation of the wind pressure coefficients can be seen in Appendix K (based on wind pressure coefficients provided by Sbi 202). The values are chosen based on the assumption the dynamic software uses the same values in the dynamic simulations. The wind speed used in the calculations is Monthly mean wind speed currently provided in the BE15 weather file.

On the following diagrams can be seen the air flow values calculated with various temperature differences and coefficients for Attempt 1.

Option 1 results shown on the graph below exhibit slight changes of value throughout the various simulations with different temperature difference. Due to the fact the values of the simulations with a ventilation zone temperature of 24 °C and room temperatures (which are around twice as much), are similar, leads to the conclusion wind speed is the driving force in the calculations. In order to verify that conclusion a calculation is made and the driving force can be seen in the table shown in red under simulation for Option 1. The calculation shown is done with the highest ventilation zone temperature difference. For additional calculations regarding Option 1 to 4 refer to Appendix F.2.

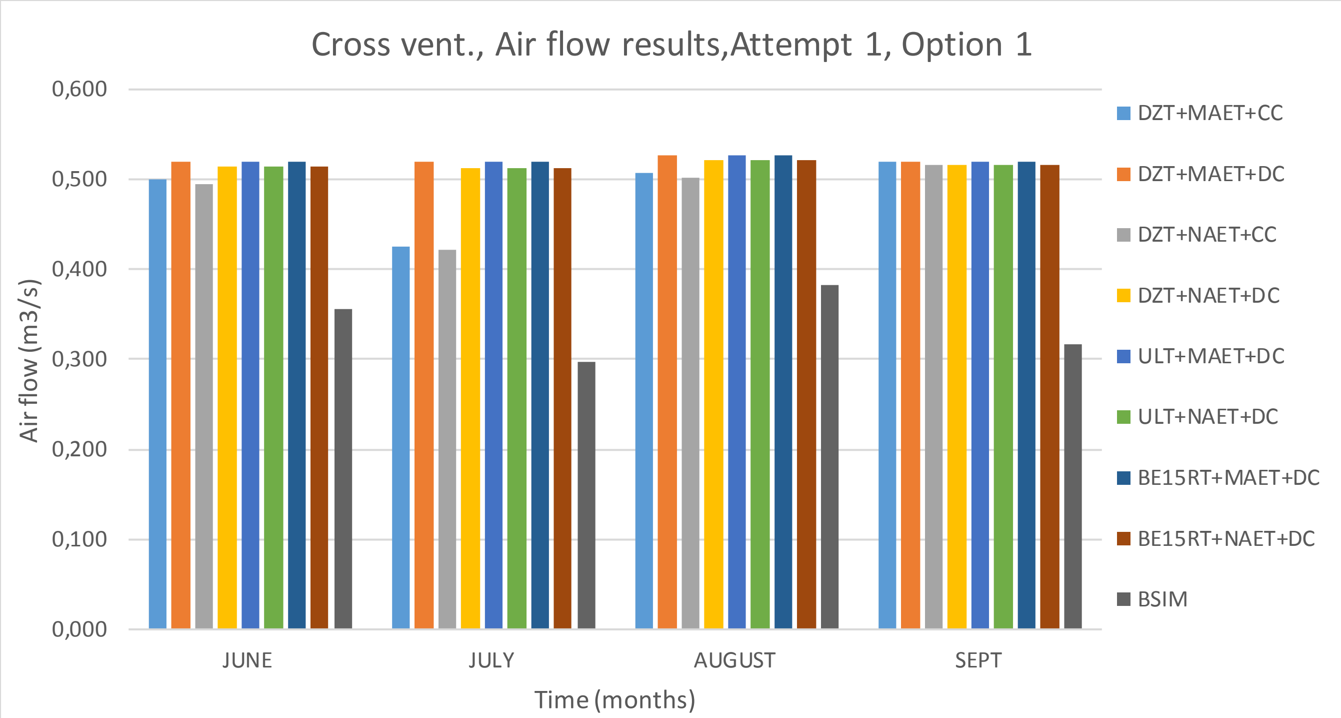

Figure 28-Cross vent., Air flow results, Attempt 1, Option 1

The equation stated below is used for the calculation of air flow for cross ventilation principle. The mathematical phrase in brackets is used for the determination of the driving force. As in single sided ventilation calculation, the maximum of the two expressions is taken and used further in the calculation.

Equation 11

$$q_{V;\mathrm{arg;in}} = 3600 \times \frac{\rho_{a;\mathrm{ref}}}{\rho_{a;e}} \cdot \boxed{\max\left(C_{D;w} \cdot A_{w;\mathrm{cros}} \cdot \min\left(u_{10;\mathrm{site}}; u_{10;\mathrm{site;max}}\right) \cdot \left(\Delta C_p\right)^{0,5}; \frac{A_{w;\mathrm{tot}}}{2} \cdot \left(C_{st} \cdot h_{w;st} \cdot abs\left(T_z - T_e\right) \right)^{0,5} \right)}$$

OPTON 1	JUNE	JULY	AUGUST	SEPT
BE15 room temp+ MAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,6170	0,5188	0,6170	0,6591
Temperature difference (ΔT)	14,97	12,52	11,92	12,86
calculation	0,1489	0,1362	0,1329	0,1380
BE15 room temp+ NAET+DC				
Wind speed (m/s)	3,52	2,96	3,52	3,76
calculation	0,6170	0,5188	0,6170	0,6591
Temperature difference (ΔT)	17,97	16,00	14,97	15,27
calculation	0,1631	0,1539	0,1489	0,1504

Table 33- calculation of driving force for BE15 room temperatures for Option 1

The comparison shows higher values for wind speed force. Taking into consideration the calculation is done with the highest temperature difference for the option and the wind speed is 3 to 5 times larger than buoyancy, it can be concluded for this case study the driving force for cross ventilation is wind speed.

The 16798-7 results exceed the results obtained from BSim. They surpass the dynamic simulation software vales and are around 27 to 42 % greater in the simulated period for Option 1. Because of the derived difference further investigation is done in attempt to reduce the 16798-7 values, leading to performing Attempt 2.

Attempt 2 is a simulation done for all options, with different temperature differences and wind pressure coefficients received and taken from BSim simulations. Due to the air flow being wind driven, the difference in wind pressure coefficients has a direct effect on it. Therefore in the following attempt a monthly night mean difference in pressure coefficients is used. In table 34 can be seen the wind pressure coefficient differences used in the simulation for he different months. Wind speed is kept as Monthly mean value.

Parameter/ Month	June	July	August	September
ΔCp	0,321	0,326	0,322	0,322

Table 34-delta Wind pressure coefficients from BSim

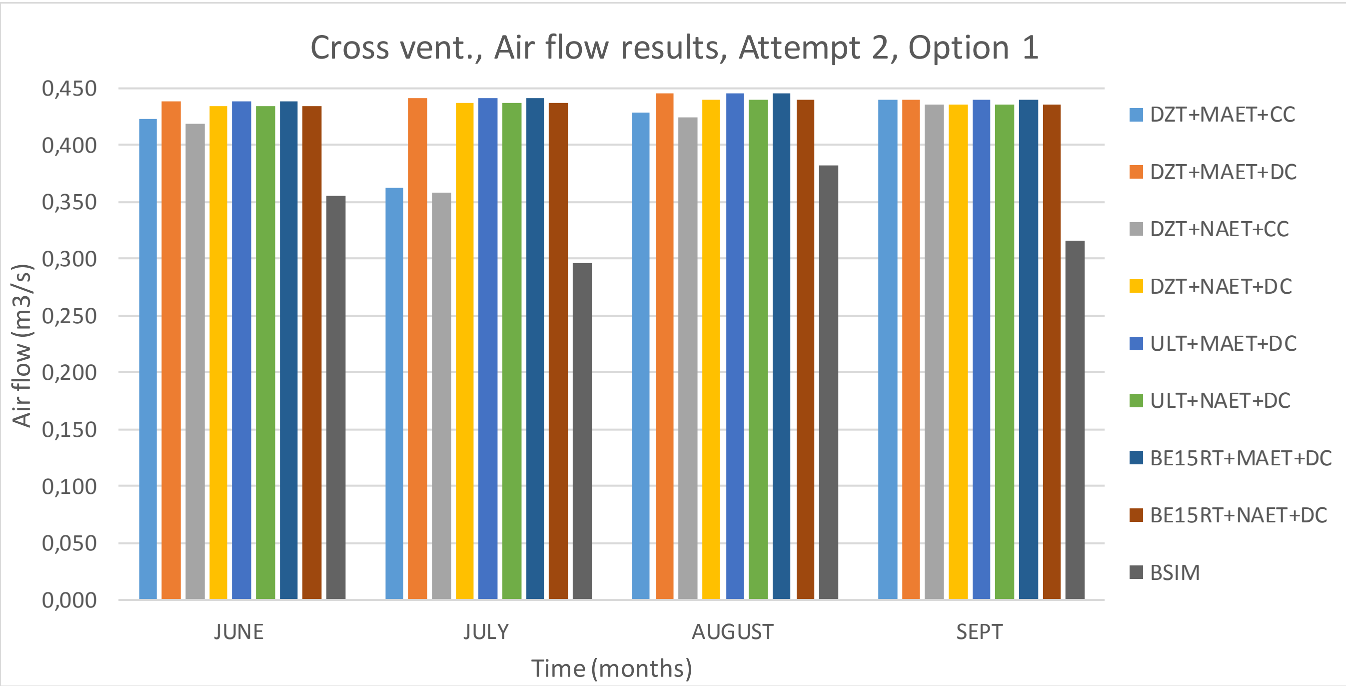

Figure 29-Cross vent., Air flow results, Attempt 2, Option 1

From the representation of results on figure29 a fall in air flow is noticed.

Air flow received from 16798-7, using similar difference in wind pressure coefficient as BSim, has decreased, compared to Attempt 1, with around 13% for Option 1. Thus making the flow between 14 and 33% higher than Bsim simulations. Nevertheless it is still larger than the air flow from the dynamic simulations.

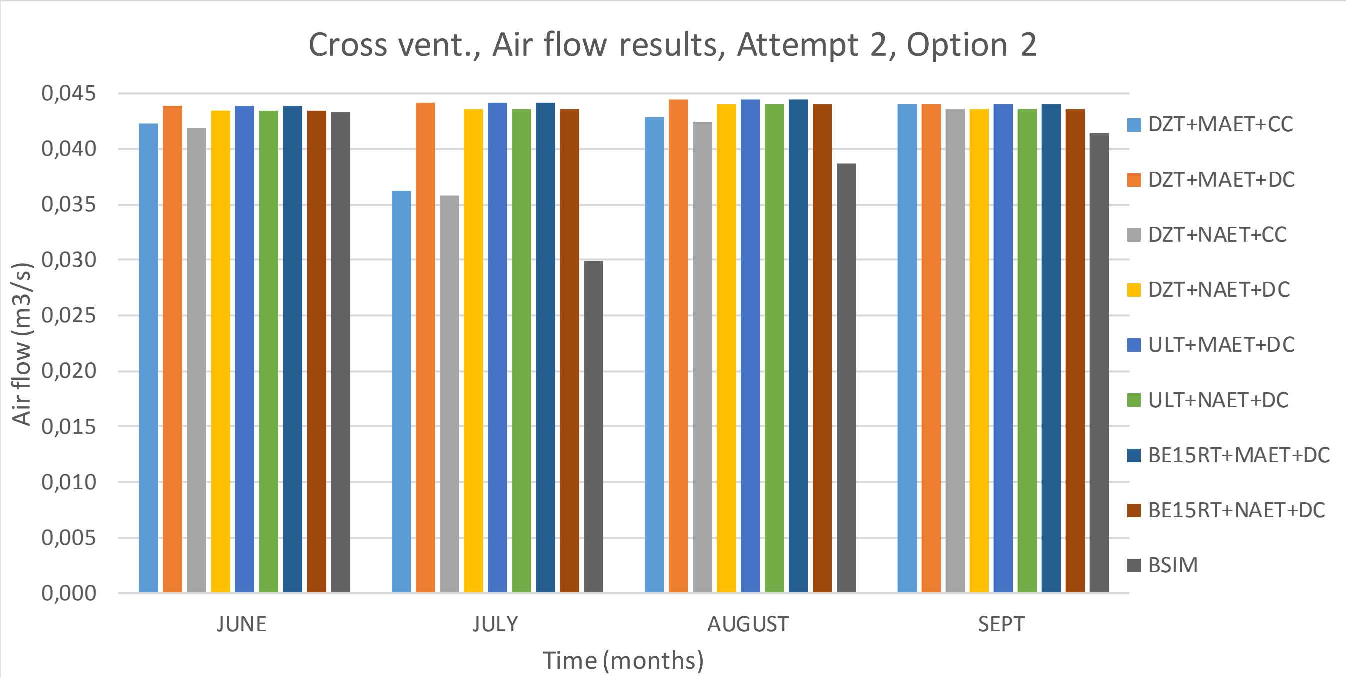

Figure 30-Cross vent., Air flow results, Attempt 2, Option 2

The difference in values in Option 2 is smaller between the two simulation programs.

Considering wind speed is another parameter that can be changed and has a direct effect on the calculation an additional attempt was done, applying a different wind speed.

Attempt 3 consists of simulations done with various ventilation zone and external temperatures, monthly night mean difference in wind pressure coefficients similar to BSim and an implementation of wind speed corresponding to the particular time simulated. The Monthly night mean wind speed was retrieved from DRY 2013 weather file, used in BSim. Table 35 shows the new values implemented in 16798-7.

Parameter/ Month	June	July	August	September
Wind speed m/s	3.45	2.53	3.20	3.48

Table 35- monthly night mean windspeeds from Bsim

The results for Option 1 and 2 show further decrease of air flow as seen on figures 31 and 32. In Options 1 to 4, in 56% of the simulations the dynamic flow is higher. Considering BSim calculates with hourly values and the results shown on the graph are Monthly mean night air flows, a deeper examination of the results was done. Periods with the same wind pressure coefficients and wind velocity are compared to see the difference in air flow between the 16798-7 and BSim.

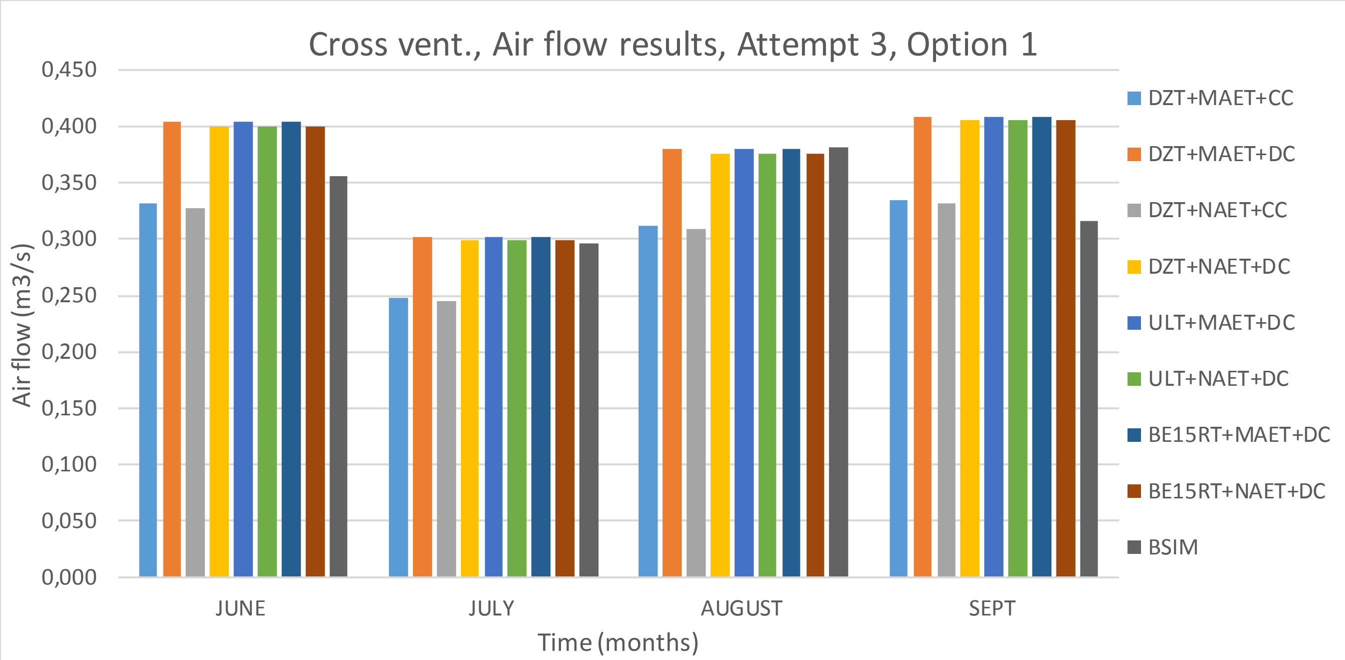

Figure 31-Cross vent., Air flow results, Attempt 3, Option 1

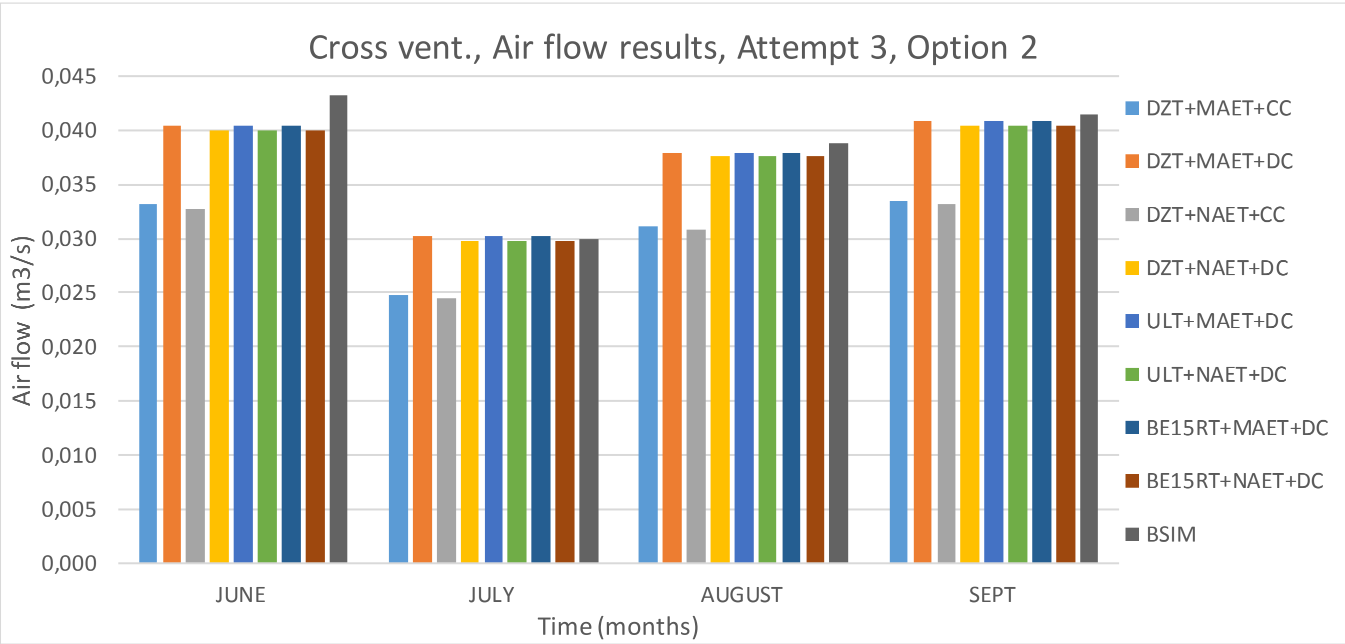

Figure 32-Cross vent., Air flow results, Attempt 3, Option 2

From the comparison for Option 1 on an hourly basis, with similar parameters as possible, is seen in 75% of the simulation period BSim calculates higher air flow. The parameters derived and compared from the simulations can be seen in table 36. For further Options refer to Appendix F.4 and F.5.

Months/Parameters	**ΔCp (-)**		**Ext. temp. (°C)**		**Wind speed (m/s)**		**Air flow (m3/s)**	
Tool	**BSim**	**16798-7**	**BSim**	**16798-7**	**BSim**	**16798-7**	**BSim**	**16798-7**
June	0.320	0.321	13.6	11.23	3.4	3.45	0.401	0.328-0.404
July	0.327	0.326	14.8	14.4	2.5	2.53	0.305	0.245-0.302
August	0.322	0.322	15.4	14.93	3.30	3.20	0.404	0.309-0.380
September	0.325	0.322	8.1	12.13	3.50	3.48	0.409	0.332-0.408

Table 36-Parameter comparison

11.4 Simulation analysis compared to SBi 213 airflow value suggestion

As calculated in section 6.1, airflow suggested in SBi 213 for night ventilation with manually operated windows is as follows:

Air flow for night ventilation calculated on a building level is 0.055 m3/s.

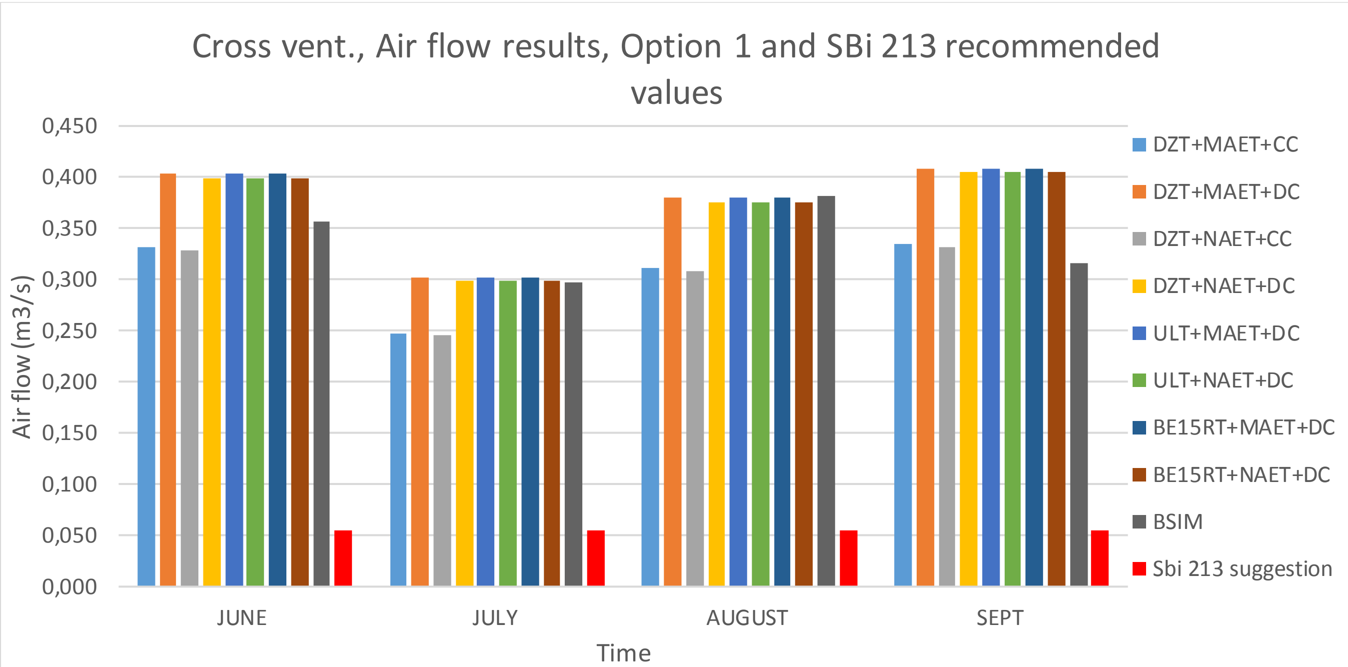

Figure 33-Cross vent., Air flow results, Option 1 and SBi 213 recommended values

The calculation of effective opening area, done in Appendix D, of the options for Cross ventilation show Option 1 and 4 covering the necessary criteria and suitable for the particular natural ventilation principle.

Throughout the comparison of Cross ventilation simulation a particular tendency was observed. Option 2 and 3, are overestimated by the SBi and Options 1 and 4 underestimated with 4 to 7 times in the different simulations. Graphical representation can be seen in Appendix G.5.

Results and Discussion 12

The results derived from a total of 1800 simulations are challenging. The two natural ventilation principles tested show opposite tendencies when calculating the air flow. Single sided ventilation underestimates and cross ventilation overestimates the results. The underestimation is not investigated further due to the calculation methodology of 16798-7. The most beneficial part of the process was to establish the extent of how different parameters correlate and affect the flow.

12.1 Impact of the different parameters

The first parameter to be changed were the wind correction factors. These parameters dealt with the topography and roughness of the terrain. The default coefficients suggested take 80% of the meteorological wind speed at 10 m height. Due to the recommendation of calculating the coefficients according to ISO 15927-1. On a general level it was established they use 14% less of the wind speed compared to the default values. This results in air flow being higher from default coefficients in comparison to calculated ones. The use of the proper coefficients according to terrain has an evident effect on the air flow.

Throughout the simulation process for single sided ventilation it was apparent that using the proper temperature is essential. As an example from Option 1 in June, with an increase in temperature difference (between internal and external temperatures) used in the flow calculation, a 7% higher value is gained, producing a flow closer to the assumed correct BSim value.

In regards to internal temperatures, simulations were performed with design room temperatures as recommended by the DS 418, recommended night cooling temperatures form the 13790, upper limit temperatures from the BR15 and room temperatures from the BE15. The design temperatures were consistently lower than the BSim air flows, with the BE15 room temperatures showing the greatest potential to reach the BSim results, when air flows are buoyancy driven.

When analysing the cross ventilation air flows, two parameters stick out- the wind pressure coefficient and the wind velocity. The wind pressure coefficients were changed twice throughout the simulations. Once with values provided by SBi 202 and the second time with monthly night mean values derived from BSim. When the simulations were done with a ΔCp of 0.45, the results were overestimated by 46% for Option 1 in June. The simulations done with the BSim ΔCp, they showed air flows 23% lower, compared to the 0.45 simulations. There was no need to simulate the recommended ΔCp of 0.75 from the pre standard, when the 0.45 was already overestimating. Therefore the Cp coefficients have a large impact on air flows regarding cross ventilation.

When air flows are velocity driven, the external velocities play a crucial role in the air flow calculating. The simulations show a 10% decrease, bringing the air flow results closer to the BSim when the Monthly night mean velocities were used.

12.2The new parameters proposed for usage in BE15

To integrate the 16798-7 into the BE15 would require additional inputs from the user. Currently, energy consultants, use architectural drawings when making the energy frame calculations for permit approval. These drawings provide the measurements for the in-depth window calculations, and boundary conditions. To add the necessary calculations for the effective opening area, the ratio Rw can be obtained by the window suppler. Room and building height can be obtained from the drawings, as well as hst.

There are two areas that could cause some problems depending on how they are integrated into the program. The Cp wind coefficients and the calculated coefficients. The Cp values could be a function from the geometry similar to the way BSim does it. Perhaps pictures of different geometrically shaped buildings could be used and by selecting the picture, the corresponding wind pressure coefficients are accessed. This could also give designers an easy platform to see the energy performance of one shape compared to another and the natural ventilation capabilities.

The calculated roughness coefficients could be an expert user feature for those few special locations. Otherwise, the default roughness coefficients have shown to be robust without jeopardising the flowrate by over estimating it.

Using window pictures with opening areas could also be a choice. This way the simulations could be compared relatively quickly. The user could see the benefit of a different type window for natural ventilation purposes. Including a box where if a safety latch is used the effective opening area is adjusted accordingly.

To summarise the majority of the 23 inputs are in line with what an energy consultant already calculates or has at his disposal. The remaining more complicated parameters need to be integrated as simply as possible for the everyday user, with an expert feature, to override certain default parameters if the need should arise.

Conclusion 13

This chapter engages with a general discussion regarding the results obtained from the research and application of the new method to calculate the airflow dependant on the effective opening area in relation to the building's physical placement. The chapter includes recommendations as a result of the study and concludes with suggestions for future studies in this area.

13.1 General discussion

The overall aim of this report was to answer the question, "Does the implementation of a simplified model succeed in delivering a method in which natural ventilation can be calculated as opposed to user defined, in BE15?" The results from the simulations have shown a clear view on where the calculated air flows stand compared to the recommended values from the SBi 213. In general the SBi underestimates the flows for single sided ventilation by 260 to 440%, when the effective opening area covers the recommended minimum. And overestimates by 49 to 75%, when the minimum for effective opening area is not met. For cross ventilation the air flow is underestimated by 370 to 610% and overestimated by 31 to 66%, considering the effective opening area. This makes it apparent, that the BE15 air flow calculations can benefit from the implementation of a calculated method.

In the case of single sided ventilation, it appears that the calculation method provided in the 16798-7 underestimates the airflows. This is not necessarily a negative. Considering, the calculation method needs to be versatile, underestimation in the airflows could be considered a safe measure. However, when analysing the results from the cross ventilation, an overestimation in airflows was observed. This could provide a better then possible result and therefore a second set of simulations was done in the cross ventilation simulations. The second set investigated airflows based on an accurate parameter input. The results from 128 calculations showed that when the parameters were equivalent with each other, the calculated airflows in 6 calculations, were overestimated airflows while the remaining 122 calculations were equivalent or lower than BSim airflows. Showing that when all the parameters are similar the calculation method proposed in the 16798-7 can deliver comparable airflows to BSim.

Considering that the BE15 presently, does not account for the terrain in the calculations, introducing airflow calculations that implement the factors in their calculations provide a more specific result from the BE15 simulations. As was seen in the simulations with regards to the wind correction factors that consider the topography and roughness of the site, the calculated results were lower than the default values. As stated earlier, the calculated coefficients are provided for the case study whereas the default values are considered generic. It is worth noting though, that there is the possibility to calculate closer to reality if the site provided a challenging terrain.

To surmise, neither system is perfect nor are the simulations 100% accurate. Various simulations were done using different natural ventilation strategies, ventilation zone temperatures, external temperatures, wind velocity and wind pressure coefficients. They were performed both on a building level and thermal zone level, depending on the strategy. These new inputs are inline with considerations that energy consultants use in their area of work. The advantage of seeing natural ventilation principles simulated effortlessly in the BE15 model could aid users in considering natural ventilation options in their designs early in the design process.

Although every effort was made to try and evaluate the BE15 and BSim results, without rewriting the spreadsheet to allow for the airflow in the Family type, the comparison could not be made. It is therefore recommended that if the 16798-7 is to be integrated into the BE15 program, the BE15 spreadsheet needs to be updated accordingly for a proper validation to be performed. Rewriting the BE15 spreadsheet was not in the scope of this report.

Further studies need to be done before the implementation of the 16798-7 into the BE15. This report however, shows that the future studies are warranted into this area.

13.2 Recommendations

As mentioned earlier in chapter 2, the DMI uses three weather stations to define the weather file used in the energy calculations. The weather stations are chosen to represent the largest population not the average weather conditions. And as the Appendix N, there is a figure that clearly shows the weather stations are not representative of Vejle where the case study is. A recommendation is suggested that the DMI could provide a weather file, using three weather stations, for the different geographical areas of Denmark. After all the west coast of Jutland has different weather conditions then the land locked interior.

The BE15 has access to the same weather file as BSim, yet uses only the mean monthly daily temperatures in its calculations. Figure 1 clearly shows the temperature differences between the nightly average monthly temperatures and the daily average temperatures. The results from the simulations show that for sensitive calculations like those made for cross ventilation the use of the nightly average temperatures are within accepted differences. It is therefore recommended that for night cooling calculations in the BE15, the program is updated to use nightly mean average monthly temperatures. The same recommendation is made for Monthly night mean velocities.

13.3 Further Research

As further research is suggested in connection to cross ventilation simulation, using the Multi zone modelling in the dynamic software. This type of model will allow a more detailed and realistic simulation, taking into consideration internal doors, opening and air flow transfer throughout the zones.

Testing the calculation method in multiple case studies with different building form and the ability to implement and test stack ventilation could lead to interesting results.

Further simulations are recommended, using a case study that represents an average home in Denmark. A custom case study as the one used for the current simulations may lead to unfavourable data outcome.

Due to the big differences between recommended values from SBi 213 and calculated airflows for night ventilation, it would be interesting to investigate if the same tendency is present during occupied hours.

List of Figures

List of Tables

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