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SUPPORT THE DISSEMINATION AND ROLL-OUT OF THE SET OF ENERGY PERFORMANCE OF BUILDING STANDARDS DEVELOPED UNDER EC MANDATE M/480

Report on Case Study to EN 16798-7 and EN 16798-5-1 Mechanical Ventilation

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Abbreviations and acronyms in this document:

AHU	**Air handling unit**
CA-EPBD, CA-5	**Concerted Action EPBD V**
CEN	**European standards organization**
EN	**European standard**
EPBC	**Energy Performance of Buildings Committee (C09300)**
EPBD	**Energy Performance of Buildings Directive**
EPB standard	**Standard for the calculation of energy performance of buildings, that complies with the requirements given in ISO 52000-1, CEN/TS 16628 and CEN/TS 16629 or later updates**
GDPR	**EU General Data Protection Regulation (2018)**
ISO	**International organization for standardization**
MS	**EU Member State(s)**
NA (/ND)	**National Annex or National Datasheet for EPB standards**
NSB	**National Standards Body of CEN and/or ISO**
RER	**Renewable energy ratio**
TR	**Technical report (of CEN and/or ISO)**

1 Introduction

This document is intended to present the case study and to discuss the contents of

- EN 16798-5-1 *Energy performance of buildings — Ventilation for buildings — Part 5-1: Calculation methods for energy requirements of ventilation and air conditioning systems (Modules M5-6, M5-8, M6-5, M6-8, M7-5, M7-8) – Method 1: Distribution and generation*
- EN 16798-7 *Energy performance of buildings — Ventilation for buildings — Part 7: Calculation methods for the determination of air flow rates in buildings including infiltration (Modules M5-5)*

in combination with

- EN ISO 52016-1 *Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures (ISO 52016-1:2017),*

in order to show the effect of the mechanical ventilation calculation represented in EN 16798-5-1 and EN 16798-7 on the energy needs and internal temperature calculation.

This document is focused on the calculation of air flow rates and supply air conditions due to mechanical ventilation, in an hourly calculation interval, and their dependence from and influence on internal temperatures and on the energy needs for heating and cooling.

This case study concentrates on a small part of EN 16798-7 in the area of mechanical ventilation, forming the link between the energy needs calculation and the calculation of the distribution and generation parts of the mechanical ventilation system, calculated according to EN 16798-5-1.

The focus of the case study is on the case of load dependent control of the air flow rates or of the supply air conditions and, in this context, on the effect of the deviations of limited capacities and/or operational deviations from the actual needs. These effects are shown and discussed, based on the coupling of the three calculations.

An explanation and a summary of the results have been presented in the frame of a webinar from the EPB Center, a recording of which is available under [1].

2 Executive summary

This case study demonstrates the coupling of the spreadsheets of EN ISO 52016-1, EN 17898-7 and EN 17898-5-1, in order to represent the effects different control strategies for an air conditioning system. Especially, the mechanism of required and actual operational values such as air flow rates or supply air temperatures, is proven and demonstrated.

Two cases are calculated, for each of which a summer and a winter week is analysed:

- A load dependent variable volume flow rate with pre-defined supply temperature:
  The required volume flow rate is calculated in order to meet the cooling or heating needs of the zone. The system operation follows that required value as within its boundaries, set by the maximum design volume flow rate of the system and the minimum possible operation at 20%.
  The supply air temperature is pre-defined by an outdoor temperature dependent curve.
  The results for both summer and winter show that the required cooling or heating needs lead to high required air volume flow rates on some days. The actual air volume flow rates follow these required values except for peak situations, where the required flow rates exceed the maximum flow rate of the system. Accordingly, the cooling or heating needs are not met during these times.

- An air quality dependent 2 stage volume flow rate with load dependent control of the supply temperature:
  The required volume flow rate is calculated in order to meet the air quality requirements depending on the occupation in the thermal zone, representing a CO_2-dependent control with a control inaccuracy. The system operation follows that required value by switching between 100% and 66% of this value so that the value is always above the required value. The required supply air temperature is calculated in order to meet the cooling or heating needs of the zone. The system operation follows that required value as within its boundaries.
  The results for both summer and winter illustrate that the supply air volume flow rate shows the 2 stage operation of the system, which follows the occupation schedule. The required cooling or heating needs lead to low or high required supply air temperatures at some times. The actual supply air temperatures follow the required values, except for the peak situations, where they reach the limit. Accordingly, the cooling or heating needs are not met during these times.

The case study is restricted to a few specific parameter settings for an air conditioning system. This functionality could be proofed. The results show the expected behaviour of the thermal zone under the influence of the ventilation systems, and vice versa. The order of magnitude of the calculated variables is plausible.

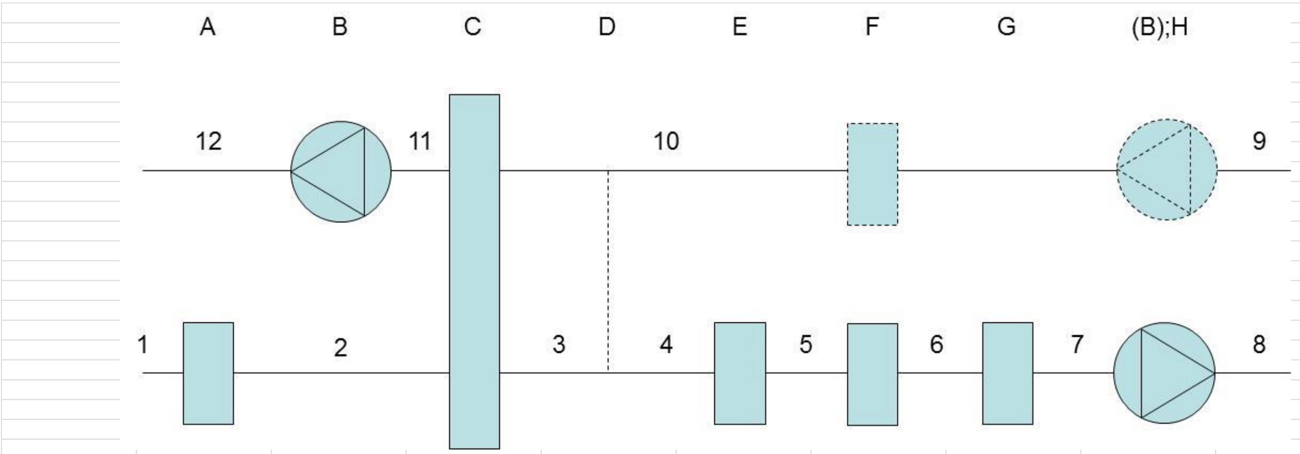
3 The context of the case study

Mechanical ventilation and air conditioning is, in general, a complicated issue for comprehensive cases. For non residential buildings, where rather complete (and therefore complex) air conditioning systems can be installed, it involves a rather extensive calculations, and so is the calculation method according to EN 16798-5-1. The methods for calculation of the air conditioning systems given in EN 16798-5-1 include

- Air flow rate control types
- Supply air temperature control types
- Heat recovery:
  - Types:
    - flat plate
    - Rotary
    - Pumped circuit

    -> there is a connection to product standards (EN 308, 13053)
  - Humidity recovery
  - Control
  - Frost protection
  - Auxiliary energy
- Recirculation control
- Fan control
  - Single zone / multi zone systems
  - Link to product standards
- Ground preheating / -cooling
- Humidification / dehumidification
- Adiabatic cooling

From the above list, it can be seen that this leads to a very comprehensive standard, ad so is the related spreadsheet: it involves more than 150 equations, offers a vast number of options and a vast number of combinations, and requires the respective number of characterisation of components. This leads to the need for a relatively user friendly interface, which has been added to the spreadsheet from the beginning, in form of a drop down menu, attached to a system scheme originating from the standard, which is shown in Figure 1.



General	A	B	C	D	E	F	G	H
Volume flow rates	Frost protection / ground preheating/-coo-ling	Exhaust air fan	Heat recovery	Recirculation	Cooling / dehumidification	Humidification	Heating	Supply fan
Detailed								
Air handling unit localosation	Ground air preheating and -cooling	localisation	Heat recovery type			Humidifier type		Fan motor localisation
NC	NONE	UP_HR	ROT_HYG	yes		CONTACT		OUTS_AIR
Supply air temperature control	Frost protection type		only for FLAT_PLATE and ROT_HYG	Recirculation control		humidifier control		System type for variable air volume flow rate fan energy calculation
ODA_COMP	PREH		Residential	VARIABLE		ON_OFF		SINGLE_ZONE
Control of the volume flow rate	Control of the frost protection		Control of the heat recovery device			humidification energy carrier		Control of the fan
ODA_COMP	INDIRECT		SPEED			HUM_CR_EL		DIRECT
System type						Adiabatic cooling		localisation
else						no		UP_HR

Figure 1: Scheme and attached drop down menu from the EN 16798-5-1 spreadsheet

In EN ISO 52016-1, the air flow rate and the supply air conditions due to mechanical ventilation entering a thermal zone is an input, originating from "module M5-5", represented by EN 16798-7 within the set of CEN EPB standards.

In EN 16798-7, the calculation of the air flow rates covers both natural and mechanical ventilation. The scope is the "emission" part of the ventilation service, which means exactly the determination of the air flow rates and, in case of mechanical ventilation, for certain system configurations the determination of the supply air conditions to a thermal zone. The natural part is not considered in this case study. For the mechanical ventilation, certain option choices, especially in relation to control issues covered by the standard, are included.

The focus is on the cases, where a correct calculation is only possible by using the coupled calculation as shown in this case study. Details are explained in section 4.2 below.

Mechanical ventilation and air conditioning is, in general, often an effect strongly varying in time. Therefore, longer calculation intervals, such as monthly calculations, always require either the approach of estimated constant values or a statistical analysis of the conditions, which leads to the indirect consideration of short time interval values (such as hourly), e.g. in form of even multi-dimensional bin methods. Thus, this topic is one of the predestined effects to demonstrate the value of an hourly (or sub-hourly) calculation interval.

The coupling of the three spreadsheets of the above-mentioned standards demonstrates that the calculations, their interactions and the data exchange are working as intended.

4 Coverage of the scope

4.1 Introduction

The criteria to evaluate the intended scope of EN 16798-7 are straightforward:

Since the scope of the standard is the calculation of the air flow rates and/or the supply air conditions, these can be directly taken as criterion.

However, the criteria to evaluate the performance of the coupling of EN 16798-5-1, EN 16798-7 and EN ISO 52016-1 is, besides the flow rates and/or supply air conditions, the effect of these on

- the energy needs for heating or cooling,
- the indoor air temperatures

on an hourly basis, both standard results from the EN ISO 52016-1 calculation.

4.2 Coupling and complementing

The coupling of the calculation procedures is explained in more detail in section 6.1. The principle of the coupling and the involved data exchange is shown in Figure 2.

The coupling of the three calculations is done and demonstrated for a setting, where either the air flow rate or the supply air temperature depends on the energy needs for heating or cooling. This refers to a certain control scheme, which in practise would involve a zone based controller setting the variable air flow rate or supply air temperature (only one of them, the other being set independently, see section 5.3 below for more details). In the simplified hourly calculations, the control loop is not modelled; instead, the required flow rate or supply air temperature is calculated on the base of the hourly energy needs for heating or cooling. This translation is done in the EN 16798-7 mechanical ventilation part.

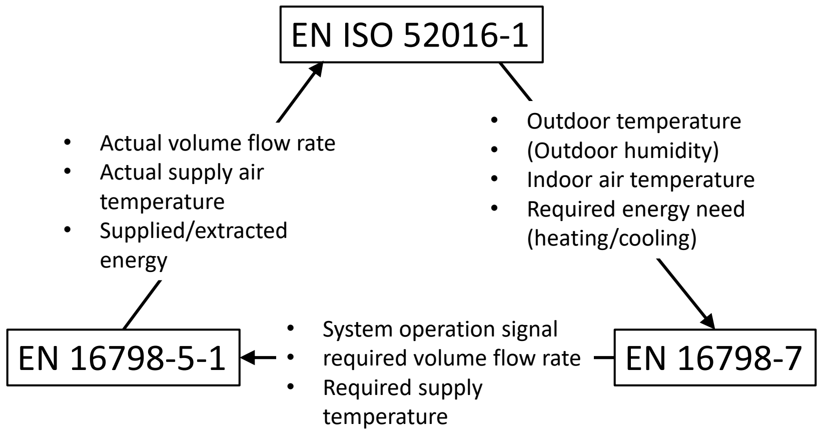


Figure 2 Principle of the coupling of the calculation modules

This principle clearly shows the iterative nature of the coupling:

- Two results from the EN ISO 52016-1 calculation – the indoor operative temperature and the **required** energy need for heating or cooling – are transferred to the EN 16798-7 module in order to perform the calculation of air flow rate and/or supply air temperature;

- The result from the EN 16798-7 calculation – the resulting **required** air flow rate or **required** supply air temperature – is transferred to the EN 16798-5-1 calculation, in order to calculate the resulting **actual** air flow rate or **actual** supply air temperature, which can deviate from the **required** values, depending on its operational settings.
- The result from the EN 16798-5-1 calculation – the resulting **actual** air flow rate or **actual** supply air temperature – is transferred back to the EN ISO 52016-1, in order to repeat the calculation with the new flow rate and/or supply air temperature.

More data transfers from EN ISO 52016-1 to EN 16798-7 are shown in Figure 2. A part of these data – the climatic conditions – are actually common input data to all calculations. They are transferred to make sure that all calculations use the same climatic conditions. The transfer is not mandatory, it can be assured by feeding all calculations with the same data in the beginning. So, there is actually one variable to be transferred each way. Another part – the thermal zone air temperature – is needed in EN 16798-5-1 to calculate the return air temperature and its influence on the supply side, e.g. by heat recovery, and on the ventilation energy use.

In practise, the data transfer is not exactly done as shown in the simplified scheme of Figure 2. Details are given in section 6.1.3 below.

The iterative nature of the coupling is an issue that occurs in different places of the overall calculation by coupling the different modules. No specific technique is given in the standards for this. However, an implementation of the coupled modules in a software will require such technique to be implemented. There are available in the literature, and software developers are familiar with them.

In this case study, which is intended to demonstrate the nature of the coupling, these iterations are avoided by simplifications (see section 6 below).

5 Definition of the cases

5.1 Rationale of the selection of cases

For the demonstration of the intended effects, a simple case of a single thermal zone in a non residential building is sufficient. The effects are portable to any other cases of more complex buildings and other types of natural ventilation openings. The technique remains the same, some of the parameters may differ.

The addition of complexity would rather hinder the understanding of the mechanism, therefore the case was kept as simple as possible.

5.2 Types of buildings

The building considered is a single thermal zone of a non residential building with 150 m² net conditioned area, 345 m³ net heated volume. The nature of the building itself is of minor interest in this case and therefore is not further described in detail.

5.3 Technologies

Three configurations of the mechanical ventilation/air conditioning system are considered:

1. A variable volume system with the flow rate controlled according to the energy needs for heating or cooling between 20 and 100%. The supply temperature for this case is pre-defined, i.e. set to an outdoor-dependent curve between 17 and 32 °C.

2. A variable volume system with the flow rate controlled according to the fresh air requirement based on the occupation between 20 and 100%. The supply temperature is controlled according to energy needs for heating or cooling.
3. A 2 stage ventilation system, running at 66/100% of the flowrate, depending on the fresh air requirement based on the occupation. The supply temperature is controlled according to energy needs for heating or cooling.

It should be noted that a load based control of both the flow rate **and** the supply temperature is «bad control», unless it would be clearly sequential. This, however, is not possible in the EN 16798-5-1 / -7 standards and spreadsheets. The respective combination of settings is marked "illegal" in the input sheets of the EN 16798-7 spreadsheet.

5.4 Calculation parameters

Use profiles for occupation and internal heat sources are taken from the default profiles from EN 16798-1:2019, Annex C for the building use "Office, landscape". See section 6.1.5.1 for details.

One climate was used for the case study: the hourly climate data for the station Strasbourg, provided by the JRC, prepared for the EN ISO 52016-1 calculation according to EN ISO 52000-10 [2]. This represents an average climate for Europe.

In order to avoid long calculation times, two cases of calculations for a winter period and a summer period of 21 days each were performed. The 3 weeks periods were picked from the climatic data in such way that the last week showed the desired climatic conditions and could be selected in order to analyse and illustrate the results, the preceding 14 being used for pre-conditioning. For each of the periods, two different variants were calculated, which show a different effect as indicated in the next section.

5.5 List of selected cases and variants

5.5.1 Case 1

5.5.1.1 Load dependent variable volume flow rate with pre-defined supply temperature

The required volume flow rate is calculated in order to meet the cooling or heating needs of the zone. The system operation follows that required value as within its boundaries, set by the maximum design volume flow rate of the system (1'350 m³/h) and the minimum possible operation at 20% of this value.

The supply air temperature is pre-defined by an outdoor temperature dependent curve according to Figure 3.

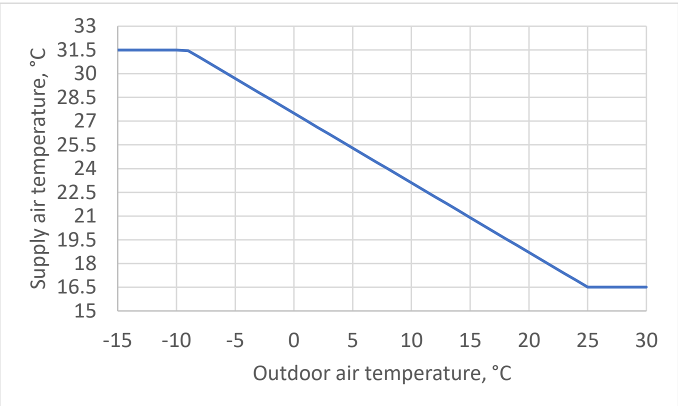


Figure 3: Set curve for the supply temperature

5.5.1.2 Variant 1: Summer period

One week in August is analysed.

5.5.1.3 Variant 2; Winter period

One week in February is analysed.

5.5.2 Case 2

5.5.2.1 Air quality dependent variable volume flow rate with load dependent control of the supply temperature

The required volume flow rate is calculated in order to meet the air quality requirements depending on the occupation in the thermal zone. This can be considered as a CO_2-dependent control. A control accuracy is assumed for this control (see 6.1.2 below for details). The system operation follows that required value within its boundaries, set by the maximum design volume flow rate of the system (1'350 m^3/h) and the minimum possible operation at 20% of this value.

The required supply air temperature is calculated in order to meet the cooling or heating needs of the zone. The system operation follows that required value as within its boundaries (min. 16.5, max 31.5 °C).

5.5.2.2 Variant 1: Summer period

One week in August is analysed.

5.5.2.3 Variant 2; Winter period

One week in February is analysed.

5.5.3 Case 3

5.5.3.1 Air quality dependent 2 stage volume flow rate with load dependent control of the supply temperature

The required volume flow rate is calculated in the same way as for case 2. The system operation follows that required value by switching between stage 2 at 100% of the maximum design volume flow rate of the system (1'350 m^3/h), and stage 1 at 66% of this value (900 m^3/h) in such way that the value is always above the required value.

The supply air temperature is controlled in the same way as for case 2: The required supply air temperature is calculated in order to meet the cooling or heating needs of the zone. The system operation follows that required value as within its boundaries (min. 16.5, max 31.5 °C).

5.5.3.2 Variant 1: Summer period

One week in August is analysed.

5.5.3.3 Variant 2; Winter period

One week in February is analysed.

5.5.4 Calculation cases summary

The table of the calculation cases is given in the Table 1.

Table 1: List of considered cases

CASE	Season	Air volume flow rate control	Supply temperature control
VAV_VLD_TOD_S	summer	Variable, load dependent	Pre-defined, outdoor temperature dependent
VAV_VLD_TOD_W	winter	Variable, load dependent	Pre-defined, outdoor temperature dependent
VAV_VAQD_TLD_S	summer	Variable, air quality dependent	Load dependent
VAV_VAQD_TLD_W	winter	Variable, air quality dependent	Load dependent

2ST_VAQD_TLD_S	summer	2 stage, air quality dependent	Load dependent
2ST_VAQD_TLD_W	winter	2 stage, air quality dependent	Load dependent

6 Calculation details

6.1 Calculation tools

6.1.1 EN ISO 52016-1 spreadsheet

An enhanced version of the spreadsheet about EN ISO 52016-1 has been prepared for the case study. A coupling routine was added to the code and an interface for the data exchange with the coupled spreadsheets was added, firstly for the coupling with the heat pump calculation [3], then generalised and extended for natural ventilation with the EN 16798-7 spreadsheet. The EN ISO 52016-1 acts as the "master" spreadsheet, controlling the data exchange and the launch of the "slave" spreadsheet(s) calculations, in this case the EN 16798-7 mechanical ventilation and the EN 16798-5-1 calculations.

An additional sheet "EN_16798-7" contains the information on the data exchange (see Figure 4):

- Which data from which sheet is to be transferred to the respective column in the "INPUT_SERIES" sheet of the "slave" spreadsheet;
- Which data is to be transferred from the "OUTPUT_SERIES" sheet of the "slave" spreadsheet to which column in which sheet in the EN ISO 52016-1 spreadsheet.

In this case study, the sheet "EN_15316-4-2", actually created for the data exchange for the heat pump calculation, is used ("misused") for the data exchange with the EN 16798-5-1 spreadsheet (see Figure 5). The mechanics is the same as for the "EN_16798-7" sheet.

As can be seen from both Figure 4 and Figure 5, data are read from and written to the sheets "EN_16798-7" and "EN_15316-4-2". This means, these sheets are used as a place to store intermediate data to be transferred between the EN 16798-7 and the EN 16798-5-1 calculations. The facility to control multiple "slave" spreadsheets in a flexible way by the EN ISO 52016-1 enabled this type of use. No change had to be done to this spreadsheet itself. Care had to be taken in respect of the right sequence of these data and the launch of the respective calculations.

WB_slave filename	Demo_EN_16798-7_2021-01-21_mech.xlsm													
Read from this WB on ISO_52016-1...				.. And write in WB_slave Input_series				Read from WB_slave Output_series		.. And write in this WB on ISO_52016-1				
Number of data		6						Number of data	5					
Description (just as info)	Sheet	Column (start from A)	First data row in this sheet	Description (just as info)	Column (start from 1st Data)	Multipl.factor	No	Description (just as info)	Column (start from 1st Data)	Description (just as info)	Sheet	Column (start from A)	First data row in this sheet	Multipl.factor
$\vartheta_{int;a}$	EN_15316-4-2	27	21	Vent.zone temp. (C)	6	1	1	Extract air flow rate required at the air terminal devices of the mechanical ventilation system	1	$q_{V;ETA;dis;req}$	EN_16798-7	19	7	1
$\Phi_{HC;nd;unlim}$	Output_t	54	6	unlimited heating/cooling need	14	0.001	2	Required supply outdoor air volume flow rate	2	$q_{V;ODA;req}$	EN_16798-7	20	7	1
Occupancy level	Input_t	7	7	Occupancy level	15	1	3	Supply air flow rate required at the air terminal devices of the mechanical ventilation system	3	$q_{V;SUP;dis;req}$	EN_16798-7	21	7	1
Supply outdoor air fraction	EN_15316-4-2	25	21	f_{ODA}	8	1	4	Operation requirement signal (ventilation) (0=fan OFF;1=fan ON)	6	$f_{op;V}$	EN_16798-7	22	7	1
Supply air temperature	EN_15316-4-2	26	21	$\vartheta_{SUP;dis;out}$	9	1	5	Required ventilation zone supply air temperature for the case of SUP_AIR_TEMP_CTRL = LOAD_COMP	7	$\vartheta_{SUP;dis;out;req}$	EN_16798-7	23	7	1
Supply air volume flow rate going to ventilation zone	EN_15316-4-2	24	21	$q_{V;SUP;dis}$	10	1	6							
							7							
							8							
							9							
							10							

Figure 4: Data transfer parameters for the coupling with the EN 16798-7 spreadsheet in the "EN_16798-7" sheet of the EN ISO 52016-1 spreadsheet

WB_slave filename	Demo_EN_16798-5-1_2021-01-21.xlsm													
Read from this WB on ISO_52016-1...				.. And write in WB_slave Input_series				Read from WB_slave Output_series		.. And write in this WB on ISO_52016-1				
Number of data		9						Number of data	5					
Description (just as info)	Sheet	Column (start from A)	First data row in this sheet	Description (just as info)	Column (start from 1st Data)	Multipl.factor	No	Description (just as info)	Column (start from 1st Data)	Description (just as info)	Sheet	Column (start from A)	First data row in this sheet	Multipl.factor
Outdoor air temp. (C)	ClimData	13	21	External temp. (C)	1	1	1	The total volume airflow rate entering the zone (m3/h)	4	$\varphi_{V;zi}$	EN_15316-4-2	24	21	1
Air moist. content	ClimData	17	21	x_e	2	0.001	2	Supply outside air fraction	8	f_{ODA}	EN_15316-4-2	25	21	1
Air moist. content	ClimData	17	21	x_e	5	0.001	3	Supply air temperature	9	ϑ_{sup}	EN_15316-4-2	26	21	1
Operation requirement signal	EN_16798-7	22	6	$f_{op;V}$	12	1	4	Energy delivered for Heating (kWh)	17	Energy delivered for Heating (Wh)	Output_t	55	7	1000
Required supply air volume flow rate per ventilation zone i	EN_16798-7	21	6	$q_{V;SUP;dis;zv;req;i}$	13	1	5	Ventilation zone return air temperature	11	$\vartheta_{ETA;zv}$	EN_15316-4-2	27	21	1
Required return air volume flow rate per ventilation zone i	EN_16798-7	19	6	$q_{V;ETA;dis;zv;req;i}$	14	1	6							
Required supply outdoor air volume flow rate per ventilation zone i	EN_16798-7	20	6	$q_{V;ODA;zv;req;i}$	15	1	7							
Required ventilation zone supply air temperature	EN_16798-7	23	6	$\vartheta_{SUP;req;zv}$	16	1	8							
$\vartheta_{int;a}$	Output_t	32	6	$\vartheta_{ETA;zv}$	17	1	9							
							10							

Figure 5: Data transfer parameters for the coupling with the EN 16798-7 spreadsheet in the "EN_16798-7" sheet of the EN ISO 52016-1 spreadsheet

The input data for the thermal zone calculation was imported from a pre-defined input data file *Demo_ISO_52016-1_Input_SFH_2020-10-05a.xlsx*.

6.1.2 EN 16798-7 spreadsheet

An enhanced version of the spreadsheet about EN 16798-7 has been prepared for the case study. In order to reduce "ballast" information for the intended purpose, the original spreadsheet was divided into two separate spreadsheets on natural and on mechanical ventilation (for the use of the former see [4]). The spreadsheet on mechanical ventilation only contains a small number of equations and the respective small number of required input data.

For the representation of the control strategy described in 5.5.2.1, additional columns were added to the "INPUT_SERIES" sheet (Figure 6), and a change was made to the variable f_{ctrl}.

					From EN ISO 52016-1		
Hour of day	Control factor	Operation requirement signal (ventilation)	Ventilation zone cooling need to be covered by the mechanical ventilation system	Ventilation zone heating need to be covered by the mechanical ventilation system	Heating/Cooling need -> split into C/H, columns G and H	Occupancy level	Occupancy
	f_{ctrl}	$f_{op;V}$	$Q_{C;V;req}$	$Q_{H;V;req}$	$Q_{HC;V;req}$		
	-	-	kWh	kWh	kWh	0, 1, 2	-
	Local	Local	M2-2	M2-2			
1	0.50	0.00	0.00	0.00	0.00	0.00	0
2	0.50	0.00	0.00	0.00	0.00	0.00	0
3	0.50	0.00	0.00	0.00	0.00	0.00	0
4	0.50	0.00	0.00	0.00	0.00	0.00	0
5	0.50	0.00	0.00	0.00	0.00	0.00	0
6	0.50	0.00	0.00	0.00	0.00	0.00	0
7	0.50	1.00	0.00	0.00	0.00	0.00	0
8	0.63	1.00	0.00	3.12	3.12	1.00	0.266667
9	0.83	1.00	0.00	2.65	2.65	2.00	0.65
10	0.83	1.00	0.00	1.53	1.53	2.00	0.65
11	0.83	1.00	0.00	0.46	0.46	2.00	0.65
12	0.83	1.00	0.00	0.23	0.23	2.00	0.65
13	0.63	1.00	0.00	0.00	0.00	1.00	0.266667
14	0.83	1.00	0.00	0.57	0.57	2.00	0.65
15	0.83	1.00	0.00	0.00	0.00	2.00	0.65
16	0.83	1.00	0.00	0.00	0.00	2.00	0.65
17	0.83	1.00	0.00	0.00	0.00	2.00	0.65
18	0.63	1.00	0.00	0.00	0.00	1.00	0.266667
19	0.50	0.00	0.00	0.00	0.00	0.00	0
20	0.50	0.00	0.00	0.00	0.00	0.00	0
21	0.50	0.00	0.00	0.00	0.00	0.00	0
22	0.50	0.00	0.00	0.00	0.00	0.00	0
23	0.50	0.00	0.00	0.00	0.00	0.00	0
24	0.50	0.00	0.00	0.00	0.00	0.00	0

Figure 6: Additional columns and control variable for demand controlled ventilation in sheet "INPUT_SERIES" (excerpt) of the EN 16798-7 natural ventilation spreadsheet

The data for the occupation level (0, 1 or 2) are transferred from the EN ISO 52016-1 spreadsheet to the second last column, and the respective occupation value calculated in the last column. From this, the f_{ctrl} variable in the second column is calculated according to the following equation:

$$f_{ctrl} = f_{occ} + 0.5 \cdot (1 - f_{occ})$$

This factor is then used to define the required air volume flow rate as a fraction of the design value. In the original EN 16798-7 standard and spreadsheet the f_{ctrl} variable is defined as varying with time "yes", but only constant values are give in Annex B. This extension was needed for this case study in order to have an occupancy dependent required air volume follow rate, which is to represent a "demand controlled ventilation" such as a CO_2 based control.

The factor of 0.5 in the above equation is arbitrary, a different value could be used. It means that the required volume flow rate does not strictly follow the occupation level, but as a consequence of control inaccuracy will be somewhere between this and the maximum (here with 0.5 in the middle).

The parameters for the control type of the volume flow rate and the supply temperature are chosen by drop down menus in the sheet "Process_design_data" (see Figure 7). Some precisions and an "interlock" in form of a message saying "illegal combination" has been added to these choices, because load dependent control of both is not possible. The settings are reported in sections 6.3.1 and 6.4.1.

Control				
Control of supply temperature (Table 8)				
4	SUP_AIR_TEMP_CTRL	LOAD_COMP		
Variable set point with load dependent compensation				
No supply air temperature control		NO_CTRL	unused	it is only distinguished
Constant supply air temperature		CONST	unused	between "LOAD_COMP"
Variable set point with outdoor temperature compensation		ODA_COMP	unused	or not "LOAD_COMP"
Variable set point with load dependent compensation		LOAD_COMP	option only to be used in combination with SUP_AIR_FLW_CTRL=ODA	
Control of supply flowrate (Table 9)				
1	SUP_AIR_FLW_CTRL	ODA		
Flow rate controlled according to outdoor air requirements only				
Flow rate controlled according to outdoor air requirements only		ODA		
Flow rate controlled according to heating/cooling load with a minimum flow rate set by outdoor air requirements		LOAD	option only to be used in combination with SUP_AIR_TEMP_CTRL ≠ LOAD_COMP and in combination with VENT_SYS_OP = BALANCED_OP or SUPPLY_OP see text and note after equation (22) in the standard	

Figure 7: Parameters for the openable windows in EN 16798-7 spreadsheet

The spreadsheet is available on EPB-Center website under the name *Demo_EN_16798-7_2021-07-12_mech.xlsm*.

6.1.3 EN 16798-5-1 spreadsheet

Only one small change had to be added to the EN 16798-5-1 spreadsheet: since the current version of the EN ISO 52016-1 spreadsheet does not include the calculation of supplied or extracted heat from the air volume flow rate and the supply air conditions. Actually, it is foreseen, but not fully implemented yet. This calculation was added to an additional column in the "OUTPUT_SERIES" sheet of the EN 16798-5-1 spreadsheet, and the calculated heat supplied or extracted is then transferred to the respective column in the EN ISO 52016-1 spreadsheet.

The parameter setting for the different cases are defined in the "SYSTEM_CONFIGURATION" sheet with the help of the drop down menus shown in Figure 1. The settings are reported in sections 6.3.1 and 6.4.1.

The spreadsheet is available on EPB-Center website under the name *Demo_EN_16798-5-1_2021-06-08.xlsm*.

6.1.4 Coupling

As outlined in section 4.2, the coupling is in principle an iterative process, which needs to be resolved when implementing the calculations in a software. It is, however, not the intention of the spreadsheets provided for the single calculation method of each module, to resolve for this iteration in the case of coupling. Some calculation modules involve iterations within the module, so in total, a full implementation of nested iterations would lead to very slow calculations.

The simplification applied in order to avoid the iteration in the present case is a time shift of 1 h. This was done by choosing the respective "first data row" for the transfer data reading as shown in Figure 4 and Figure 5 (row 6 instead of 7 for the respective data). The consequences of this are discussed blow in section A.1.

6.1.5 Supporting calculations

6.1.5.1 Use profiles

Since the EN ISO 52016-1 spreadsheet available at the time of the case study needed an operation schedule distinguishing between 3 levels, 0, 1 and 2, the schedule according to EN 16798-1 was approximated according to Figure 8 to make it compatible with the required input scheme. The last column shown in Figure 8 was transferred to the EN ISO 52016-1 input sheet "Input_p" and associated with the values 0, 7 and 17 W/m².

	EN 16798-1 - Annexes N & O												
Hour	Occupant	Appliances	Light	Dhw	Comfort required	Hsys;op	Csys;op	Vsys;op	Wsys;op	HU/DHU op			
1	0	0	0		1	3	3	1	0	0	0	0	0
2	0	0	0		1	3	3	1	0	0	0	0	0
3	0	0	0		1	3	3	1	0	0	0	0	0
4	0	0	0		1	3	3	1	0	0	0	0	0
5	0	0	0		1	3	3	1	0	0	0	0	0
6	0	0	0		1	3	3	1	0	0	0	0	0
7	0	0	0		1	4	4	4	0	0	0	0	0
8	0.2	0.2	0.2		3	4	4	4	4	4	0.266667	6.986667	1
9	0.6	0.6	0.6		3	4	4	4	4	4	0.65	17.03	2
10	0.6	0.6	0.6		3	4	4	4	4	4	0.65	17.03	2
11	0.7	0.7	0.7		3	4	4	4	4	4	0.65	17.03	2
12	0.7	0.7	0.7		3	4	4	4	4	4	0.65	17.03	2
13	0.4	0.4	0.4		3	4	4	4	4	4	0.266667	6.986667	1
14	0.6	0.6	0.6		3	4	4	4	4	4	0.65	17.03	2
15	0.7	0.7	0.7		3	4	4	4	4	4	0.65	17.03	2
16	0.7	0.7	0.7		3	4	4	4	4	4	0.65	17.03	2
17	0.6	0.6	0.6		3	4	4	4	4	4	0.65	17.03	2
18	0.2	0.2	0.2		3	4	4	4	4	4	0.266667	6.986667	1
19	0	0	0		1	3	3	1	0	0	0	0	0
20	0	0	0		1	3	3	1	0	0	0	0	0
21	0	0	0		1	3	3	1	0	0	0	0	0
22	0	0	0		1	3	3	1	0	0	0	0	0
23	0	0	0		1	3	3	1	0	0	0	0	0
24	0	0	0		1	3	3	1	0	0	0	0	0

Figure 8: Occupation and internal gains schedules approximation

6.1.5.2 Climatic data

Climatic data are calculated with EN ISO 52010-1 module, using data from the JRC data-base for the station Strasbourg (average climate).

6.2 Definitions of the cases

6.2.1 Cases analysed

From the cases as set out in section 5.5.4, only cases 1 and 3 are analysed and reported. The difference between case 2 and case 3 is not of principle nature, and due to the fact that the deviation of the actual from the required volume flow rates is bigger for the 2 stage operation in case 3, the effects intended to be shown become more explicit.

6.3 Case 1: Load dependent variable volume flow rate with pre-defined supply temperature

6.3.1 Description of the case

Parameter settings in EN 16798-7:

SUP_AIR_TEMP_CTRL = ODA_COMP

SUP_AIR_FLW_CTRL = LOAD

Parameter settings in EN 16798-5-1:

SUP_AIR_TEMP_CTRL = ODA_COMP

AIR_FLOW_CTRL = VARIABLE

All other parameters defining the system characteristics are common to all cases and not reported.

6.3.2 Calculation results

The results of the hourly calculation for variants 1 and 2 (summer and winter period) are given in Figure 9 and Figure 10.

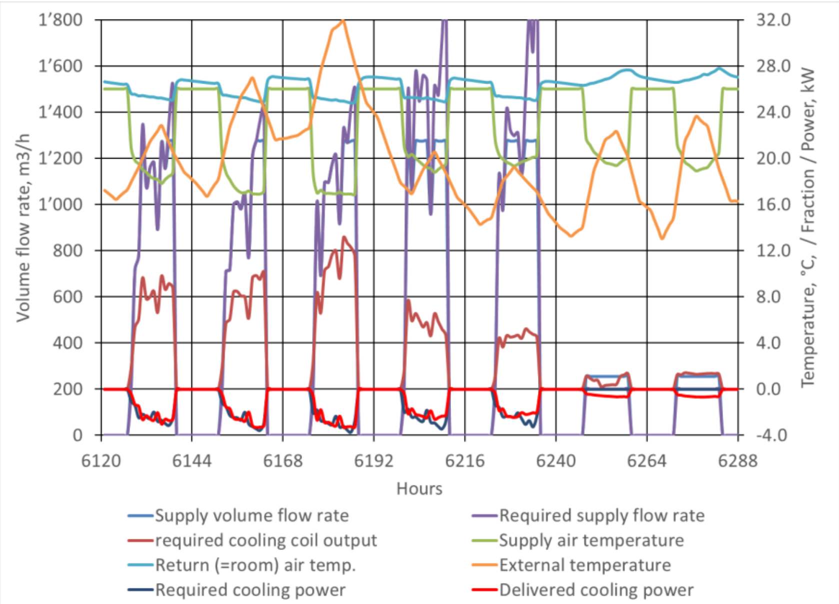


Figure 9: Hourly courses of the outdoor and indoor conditions, the required and actual ventilation air flow rate, the required and actual cooling need and the supply air temperature for a selected week for variant 1

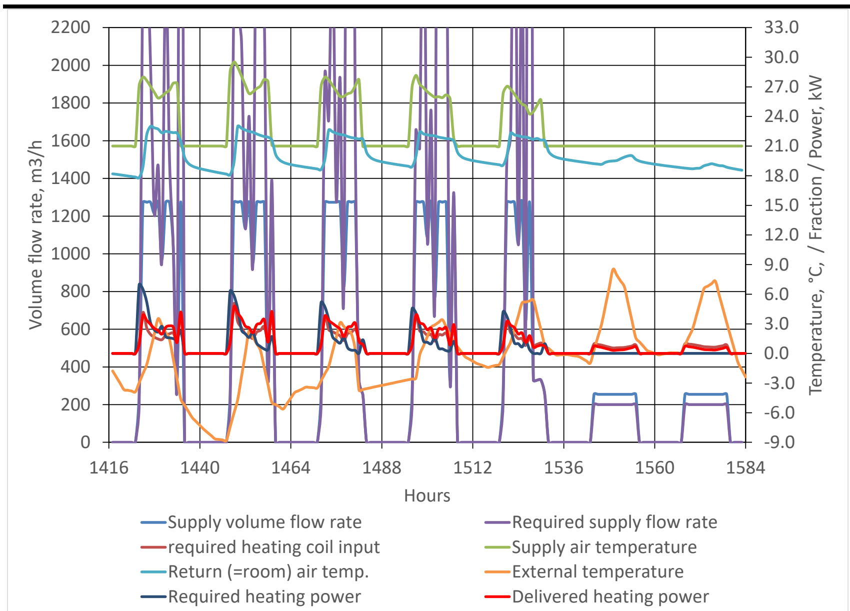


Figure 10: Hourly courses of the outdoor and indoor conditions, the required and actual ventilation air flow rate, the required and actual heating need and the supply air temperature for a selected week for variant 2

6.3.3 Discussion

In Figure 9, the following effects can be seen:

- The room air temperature is below the set point of 26°C, which is set for the operative temperature, during the operation times. This is to be expected since the heat extraction is 100% convective.
- The supply air temperature is given according to the defined curve.
- The required cooling needs in Figure 9 lead to high required air volume flow rates on days 3, 4 and 5. These required flow rates are higher on cooler days (days 4 and 5) than on hot days (day 3), because of the supply air temperature, which according to the given curve is higher on these days.
- The actual air volume flow rates follow the required flow rates, except for peak situations, where the required flow rates exceed the maximum flow rate of the system.
- Accordingly, the cooling needs are not met during the times with limited volume flow rates.
- The required cooling coil output, also shown in Figure 9, is largely different from the zone cooling needs. This is due to the additional load for the cooling down of the outdoor air and to dehumidification effects.

A similar behaviour can be seen in Figure 10 for the winter case:

- The room air temperatures are above the set point of 21°C for the operative temperature during the operation times.
- The required heating needs lead to high required air volume flow rates on all working days.
- The actual air volume flow rates follow the required flow rates, except for peak situations, where the required flow rates exceed the maximum flow rate of the system.
- Accordingly, the heating needs are not met during the times with limited volume flow rates.

- The required heating coil input is quite similar to the zone heating needs. The differences are smaller here due to the heat recovery.

6.4 Case 3: Air quality dependent 2 stage volume flow rate with load dependent control of the supply temperature

6.4.1 Description of the case

Parameter settings in EN 16798-7:

SUP_AIR_TEMP_CTRL = LOAD_COMP

SUP_AIR_FLW_CTRL = ODA

Parameter settings in EN 16798-5-1:

SUP_AIR_TEMP_CTRL = LOAD_COMP

AIR_FLOW_CTRL = MULTI_STAGE

n_{st} = 2

All other parameters defining the system characteristics are common to all cases and not reported.

6.4.2 Calculation results

The results of the hourly calculation for variants 1 and 2 (summer and winter period) are given in Figure 11 and Figure 12.

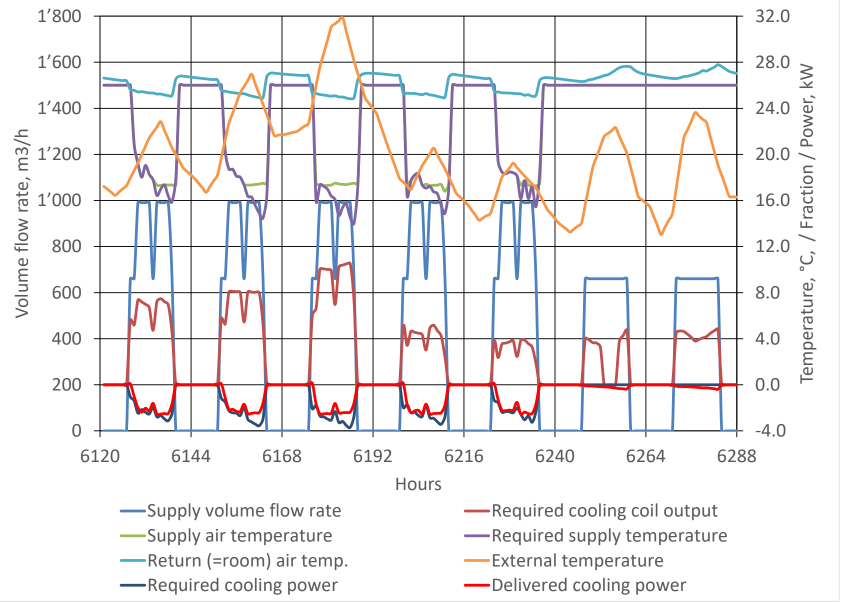


Figure 11: Hourly courses of the outdoor and indoor conditions, the required and actual supply air temperature, the required and actual cooling need and the air flow rate for a selected week for variant 1

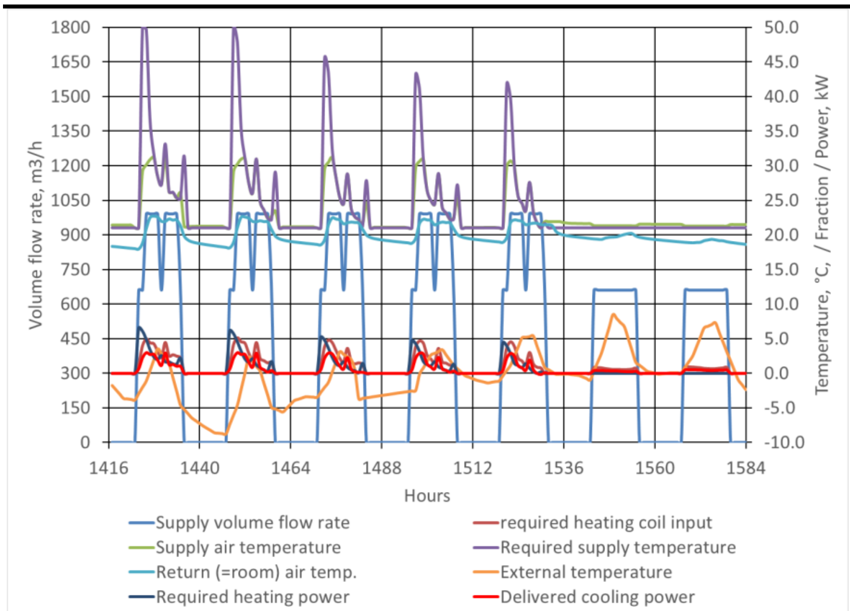


Figure 12: Hourly courses of the outdoor and indoor conditions, the required and actual supply air temperature, the required and actual heating need and the air flow rate for a selected week for variant 2

6.4.3 Discussion

Different from case1, for case 3 the following effects can be seen:

- The supply air volume flow rate shows the 2 stage operation of the system, which follows the occupation schedule. During the weekend, the system operated on stage 1.
- The required cooling needs in Figure 11 lead to low required supply air temperatures in the afternoon of all working days.
- The actual supply air temperatures follow the required temperatures, except for the peak situations, where they reach the limit.
- Accordingly, the cooling needs are not met during the times with limited supply air temperatures.

A similar behaviour can be seen in Figure 12 for the winter case:

- The required heating needs lead to very high required supply air temperatures on all working days, especially in the early morning during the heating-up period.
- The actual supply air temperatures follow the required values, except for peak situations.
- Accordingly, the heating needs are not met during the times with limited supply air temperatures.
- The zone air temperatures show a delay in reaching the level above the setpoint in the morning, due to limited heating power available.

7 Analysis

7.1 Completeness

This case demonstrates that the coupled spreadsheets of EN ISO 52016-1, EN 17898-7 and EN 17898-5-1 are able to represent the effects different control strategies for an air conditioning system. Especially, the mechanism of required and actual operational values such as air flow rates or supply air temperatures, can be proven and demonstrated, which was the main intention of this study.

The inputs and outputs are present to exchange the necessary data. Some slight changes in the EN 16798-7 and EN 16798-5-1 spreadsheets, not affecting the actual calculation methods, were necessary (such as the conversion of the unit of the zone air temperature from K to °C and adding some intermediate calculations).

7.2 Functionality

The case study is restricted to a few specific parameter settings for an air conditioning system. This functionality could be proofed.

The principle applied here can easily be adapted to other system configurations covered by EN 16798-7 and EN 16798-5-1. The results will be different, but the principle shown remains the same.

The technique of required and actual values is not restricted to ventilation and air conditioning systems. It is also present in other technical system calculations and is especially dedicated to limited power cases etc.

7.3 Sensitivity

The focus of the study is on the functionality of the coupling of the spreadsheets.

The results show the expected behaviour of the thermal zone under the influence of the ventilation systems, and vice versa. The order of magnitude of the calculated variables is plausible.

Different settings of parameters would influence the results. For example, a change of the supply temperature curve shown in Figure 3 will affect the required volume flow rates (and enable an optimisation). No further analysis of the sensitivity to such changes has been made in this study.

7.4 Usability

The input required for the EN 16798-7 mechanical ventilation calculation is minimal.

More input data are required for the detailed calculation according to EN 16798-5-1. However, the spreadsheet has some "user friendliness" due to the "system configuration" menus.

The coupling of the standards proved to be very useful for the purpose of this study.

8 Conclusions and recommendations

The standards cover adequately the scope, as far as it could be explored by this study.

The spreadsheets needed to be updated slightly for data exchange reasons and will be made available on the EPB Center website.

Annex A

Details on the coupling of the spreadsheets

A.1 Common issues of all cases

The simplification of the reference to the previous time interval for the coupled spreadsheets to avoid iterations mentioned in section 6.1.4 leads to some effects at the times of changing operational parameters. E.g. when the system is switched off at the end of the operation time of a day, some variables can show spikes, which must be expected, but are not really reflecting the expected practical behaviour and therefore hard to explain.

For this reason, some corrections have been made at single hours in the results shown in Figure 9 to Figure 12, especially for the presentation in the webinar, where time did not allow for the explanation to be given for such phenomena.

In Figure 13, the results from Figure 11 are shown without such corrections.

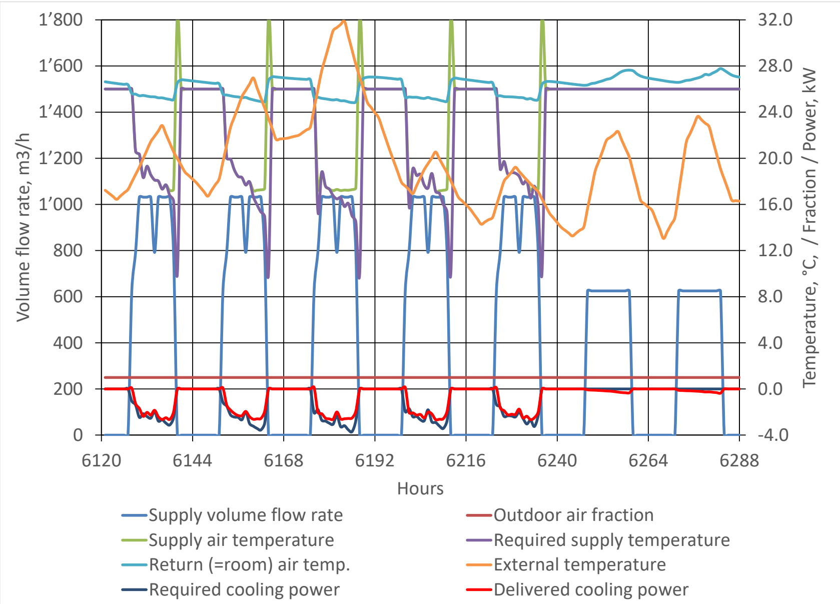


Figure 13: The results of Figure 11, without hand corrections

It can be noticed that on each day at the end of the operation of the ventilation system, there are spikes for both the required and the actual supply air temperature. Actually, this is of minor importance, since the system is not in operation. In order to avoid the respective questions, these values were corrected in Figure 11.

A.2 Alternative coupling technique

The phenomena discussed in section A.1 lead to the decision to test an alternative solution for the coupling of the spreadsheets: Instead of the coupled calculation at each calculation interval (hour), as provided by the coupling technique shown in section 6.1.1, a "handish" solution was tried, by running sequentially the 3 spreadsheets for the full calculation period, transferring the necessary data by hand from one spreadsheet to the other in between.

This technique avoids the reference to values from the previous time step, but on the other hand makes the process iterative.

Experience with the case study reported here has shown that the iteration converges quite quickly and becomes stable after 3 to 5 iterations. This makes this variant of coupling possible for the case study. But this cannot be generalised for all coupling cases.

The advantages and disadvantages of the two processes can be summarised as follows.

Technique	advantages	disadvantages
Dynamic coupling	1 run for all calculations	1 h time shift necessary to avoid iteration Long calculation time
"handish" coupling	No time shift necessary Shorter calculation times for the individual runs	"Handish" transfer of data, requiring the respective knowledge More presence time for the user, since interaction is needed between the runs

Table 2: Advantages and disadvantages of the coupling techniques

Annex B

List of supporting files

VAV_VLD_TOD_S_EN_ISO_52016-1.xlsm

VAV_VLD_TOD_W_EN_ISO_52016-1.xlsm

VAV_VAQD_TLD_S_EN_ISO_52016-1.xlsm

VAV_VAQD_TLD_W_EN_ISO_52016-1.xlsm

2ST_VAQD_TLD_S_EN_ISO_52016-1.xlsm

2ST_VAQD_TLD_W_EN_ISO_52016-1.xlsm

Demo_EN_16798-5-1_2021-01-21.xlsm

Demo_EN_16798-7_2021-01-21_mech.xlsm

EPB_Center_Webinar_10_20210202_mech_Vent_V1.pdf

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[2] TMY-ISO-52010-1_conversion_2021-01-05.zip on https://epb.center/support/documents/tmy-iso-52010-1_conversion/

[3] ENERC32017-437-SI2-785.185, Case study on EN 15316-4-2, Heat pumps
October 31, 2021

[4] ENERC32017-437-SI2-785.185, Case study on EN 16798-7, Natural ventilation
October 31, 2021

Please check the EPB Center website for the overview and most recent versions of the other case study reports.

Link: EPB Center support documents

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