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Expressing the Building Energy Systems Thermodynamic Seasonal Efficiency

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Abstract. In order to reduce impact to environment, a qualitative approach of energy saving is global aspect that is included in various forms of CO_2 emissions, primary energy limitations and benchmarks in EU and member countries policy. Exergy analysis allows expressing the quality of energy flows in comparison to ambient or other reference conditions. Despite of this valuable information, this concept is not widely used in engineering practice. The article suggests the calculation procedure for sessional or periodical thermodynamic (exergy) efficiency in relation to variable reference conditions. Knowledge about defined procedures unlocks the possibility to fill up the implementation gap for building system engineering practice where seasonal performance parameters are widely used to express efficiency. Prepared algorithm allows determining seasonal or periodic thermodynamic efficiency of individual elements and energy transfer chains in building energy systems. Defined calculation procedure workflow is suitable for integrated approach when coupled heat transfer and fluid flow processes are explored in short time steps with dynamic simulation software tools. Presented algorithm ensures result that fits in thermodynamically correct range 0-1 and helps to summarize separate time step results. By adding duration of specific conditions, this analysis enables to identify critical peak periods and base load conditions across operation period. The presented framework fills the gap in lack of systematic expression for seasonal thermodynamic efficiency and suggests the process for calculation procedures workflow.

Keywords: Exergy efficiency, seasonal efficiency, periodic efficiency, building energy system.

Conference topic: (e.g.) Energy for Buildings.

Introduction

Becoming more energy efficient is the most effective way to reduce energy demand. Therefore, heat transfer and the design of heat transfer equipment continue to be an important issue in energy conservation (Manjunath, Kaushik 2014; Yilmaz *et al.* 2001). In modern buildings, an increasing amount of the consumed energy falls on ventilation systems. Higher indoor air quality also shows requirements of ventilation (Misevičiūtė *et al.* 2016). Thermal energy recovery systems allow increasing efficiency of the HVAC systems and are almost mandatory in the efficient energy use. Heat exchangers used in the recovery systems play an important role in the capital costs, energy efficiency and size of ventilation systems. Moreover, the air-to-air heat exchangers can significantly downsize the heating/cooling equipment in new buildings (Rafati Nasr *et al.* 2015). However, heat exchangers are exposed to adverse and variable weather conditions during winter operation. For very low outdoor temperatures the condensation may be formed in the form of frost (Anisimov *et al.* 2015; Rose *et al.* 2008; Rafati Nasr *et al.* 2015). This problem commonly occurs in cold climate. Frost build-up on the energy recovery unit results in reduced airflow through the heat exchanger, reduced energy savings and potential damage to the device (Nortek Air Solutions 2015; Anisimov *et al.* 2015; Rafati Nasr *et al.* 2014). This process normally reduces the heat exchanger efficiency (Lee, Ro 2002; Rose *et al.* 2008).

The efficiency of a ventilation system is closely linked to climate, specifically to the outdoor temperature. Under certain climate conditions, a specific outdoor temperature exists at which a maximum exergy usage is achieved if the air ventilation operates throughout the heating season. It should be noted that exergy efficiency, precisely is tied to the environment temperature by its nature (Misevičiūtė *et al.* 2016). Martinaitis *et al.* (2010) proposed methodology of exergy-days for exergy analysis of buildings. This methodology was also applied to evaluate ventilation systems' exergy demand (Misevičiūtė *et al.* 2016). Besides exergy efficiency determined by exact outdoor temperature, the seasonal exergy efficiency can be introduced. Seasonal performance factor is an important indicator for system design and comparison purposes. For the case of heat pump system design the EN 15316-4-2 (2006) suggests to arrange the system which aims to have high seasonal performance factor. Seasonal performance calculation could be done to assess the time-dependent performance of energy systems under changing operation conditions over a certain time span, usually a year. By cumulating the operation conditions over the year the efficiency can be estimated (Wemhöner, Afjei 2003). There are various ways to express seasonal parameters with different system boundaries.

The efficiency of the heat recovery (HR) system is often used to calculate energy savings (Roulet *et al.* 2001). However, a nominal HR efficiency usually does not show the real situation. Nominal efficiency of the HR unit is established under the stated conditions. However, this efficiency is a moment's value, the benefit of HR equipment installation is described better by a mean efficiency of a given time period. The real efficiency of heat recovery calculated as the mean year heat recovery efficiency is less than one according to standard value (Juodis 2006). Another suggested approach is to use a global HR efficiency which is similar to the nominal efficiency but additionally takes into account air infiltration and exfiltration (Roulet *et al.* 2001). The main requirements and guidelines dealing with the heat generation system efficiencies could be found in European standards. For example the heat pump performance can be evaluated in periods that are not oriented at the time scale but on the frequency of the outdoor air temperature (EN 15316-4-2:2006). However, the existing calculation methods in European and national standardization are limited with respect to system configuration and boundary conditions (Wemhöner, Afjei 2003). Also, additional parameters should be used to point out the operating conditions of the system (Zottl *et al.* 2012).

Various methods are used to analyse heat recovery in ventilation systems (Manjunath, Kaushik 2014; Yilmaz *et al.* 2001). The increasing number of scientific publications explicitly indicates that thermodynamic (exergy) analysis is a useful tool for buildings and their service systems' sustainability evaluation (Martinaitis *et al.* 2010). It allows showing where losses occur and determine their magnitude. Here used the quantity exergy is indicated as the potential to convert energy into work (Woudstra 2016). It is the most common measure of energy quality (Gundersen 2011).

A large number of efficiencies have been proposed in thermodynamics and elsewhere to measure the quality of processes and their energy utilization (Gundersen 2011). Some of these performance parameters (rational efficiency is also known as exergetic efficiency or second law efficiency, non-dimensional numbers: merit function, specific irreversibility, fractional exergy loss etc.) used in analysis of heat exchangers are reviewed in (Manjunath, Kaushik 2014; Yilmaz *et al.* 2001). Great care must be taken in choosing such efficiencies to make sure the answers are relevant for the question needed. Another common requirement for efficiencies is that they are 0-1 normalized (Gundersen 2011). The importance of this requirement is shown in exergy analysis of heat exchangers in (Martinaitis *et al.* 2016; Martinaitis, Streckienė 2016).

Characteristics of frost formation and defrost are important not only in academic research, but also in practical applications (Lee, Ro 2002; Liu *et al.* 2016). Frost formation is affected by environmental conditions but the most important of them are the air humidity, temperature, velocity and the cooling surface temperature (Lee, Ro 2002). However, the knowledge about frost formation inside air to air heat exchangers is still unresolved and can be extended. Especially, the precise boundary temperature values, which guarantee the safe operation, are needed (Anisimov *et al.* 2015). Various strategies can be used to defrost ice formation in heat exchangers, from simple strategies such as exhaust only and recirculation frost control to more complex frost control ways that allow continuous ventilation and prevent frost formation (Nortek Air Solutions 2015; Rafati Nasr *et al.* 2014; Rose *et al.* 2008; Bantle 1987). These frost protection techniques and other new methods are described in detail in (Rafati Nasr *et al.* 2014).

Systems operating in wide interval of surrounding boundary conditions should be assessed in higher detail for the cases when performance is related to surroundings. Qualitative approach based on the second law analysis should have seasonal performance expression and it would add value for the design process. Therefore, there is a need to analyse the possibilities of more efficient methods to determine the calculation procedure of seasonal or periodical thermodynamic (exergy) efficiency in relation to variable reference conditions and real heat and mass transfer processes. All these aspects and previous researchers' works support the idea to use indicators for actual and seasonal performance of the system. This paper describes an algorithm to determine seasonal exergy efficiency. As a case study for method demonstration, ventilation air handling unit is selected. This device operates with specific function to supply fresh air at temperature set point. For this function, it requires certain amount of energy with stated quality, which is seen as exergy. The presented model takes into account the effects of the frost formation. Special attention is given to the variable reference temperature (RT) as exergy quantities depend on it.

Determination of the second law seasonal efficiency

Seasonal energy performance depends on parameters of device that serves for specific function in building service system. In order to perform calculations and determine how effective the system or component is, the function should be clearly defined and common understanding about the purpose should be developed. Then the efficiency adds value as performance indicator for determining how well the design decisions and combinations of components are for the given purpose. In order to get comparable results with possibility to recreate or modify the calculation procedures, the process with clearly determined workflow steps should be defined. An algorithm to summarize and present the workflow is shown in Figure 1. Such way helps to structure calculation procedure and reduced complexity allows identifying and focusing on value adding steps.

This workflow covers all process from the start when boundaries and initial system configuration are known till the end when seasonal performance parameter is calculated. The following sections show main highlights – procedures with input data, required steps on heat and fluid flow process, calculation of the second law parameters at each time step and seasonal performance calculations. Detailed summary of calculation steps is given in Table 1.

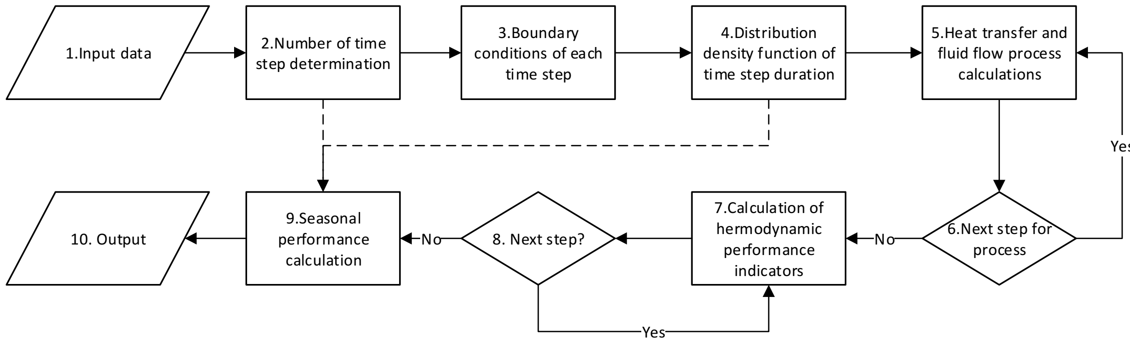

Fig. 1. Calculation workflow

Table 1. Explanations of calculation workflow

ID	Subprocess name	Subprocess definition
1	Input data	System/component function, purpose and operation aspects are identified and clearly defined in order to formulate physical and mathematical models
2	Determination of time step number	Interval (period), amount and duration of time steps is defined
3	Boundary conditions of each time step	Input parameters definition required for physical process simulation
4	Distribution density function of boundary condition duration	Statistical analysis of boundary condition distribution in order to express density function for giving the weight of specific conditions
5	Heat transfer and fluid flow process calculations	Mathematical model is defined in order to express primary variables (temperature, pressure) and secondary variables (mass flows, heat flux, etc.)
6	Calculation loop for determined steps	Repeat calculation procedures for each time step until none of the steps are left
7	Calculation of thermodynamic performance indicators	Determination of thermodynamic performance indicators at variable ambient and/or other boundary conditions
8	Calculation loop for determined steps	Repeat calculation procedures for each time step until none of the steps are left
9	Seasonal performance calculations	Expression of step weight coefficients and seasonal efficiency value
10	Outputs	Expression of seasonal parameters and other process data for further analysis, comparison or adjustment

Following subsections of the article explain the calculation procedures in detail. Finally, simple calculation demonstrating possibilities of the method is shown for ventilation system seasonal efficiency expression for different options of HR and frost prevention in it.

Boundary conditions quantification

Statistical analysis of variable boundary conditions may lead to functional relationships or possible relations, which could be used for simplification and reduction of needs to perform calculation procedures. Quantified boundary condition variables are used for determining the amount of required mathematical models and in planning of simulation procedures to obtain valid and reliable results.

Determination of calculation steps

Aggregation of input data is important step to quantify the way of following calculations steps. For the cases when examined component performance is independent from other components, there are two possible ways of calculation:

– If the performance has strong dependence of one variable and is independent from time history of variable.
– There are multiple variables influencing component performance and/or have relationship.

Required level of detailness and result accuracy guide the need to put effort on model creation. Decision to create fast with simplification assumption model may be sufficient enough if there is low level of coupling with time history, there is no or low dependence on other component outputs and performance, thermal capacity effects are small enough to neglect. If this aspect is not satisfied, transient approach should be used.

Density function of boundary conditions

The type of simulated element dictates possible option for density function expression:

- Bin method – density function expresses duration time of specific boundary condition and can be seen as $g = f(N, M, O)$
- Time series case – density is always constant and always equal to 1: $g = 1$.

Where: g is density function, N, M, O are density function arguments.

The practice of condition weighting is widely used in heat pump performance determination according standardized practice (EN 15316-4-2 2006). Reference condition variables (temperature, pressure) should be viewed in combination to other varying boundaries if they are not constant. As an example could be applied ambient temperature (could be equal to RT) which could be seen as time series data of typical meteorological year used in dynamic building performance simulation ($g = 1$) and as a statistical distribution suitable to reflect the duration of temperatures and easily adjusted via arguments to reflect different climate (see Fig. 1).

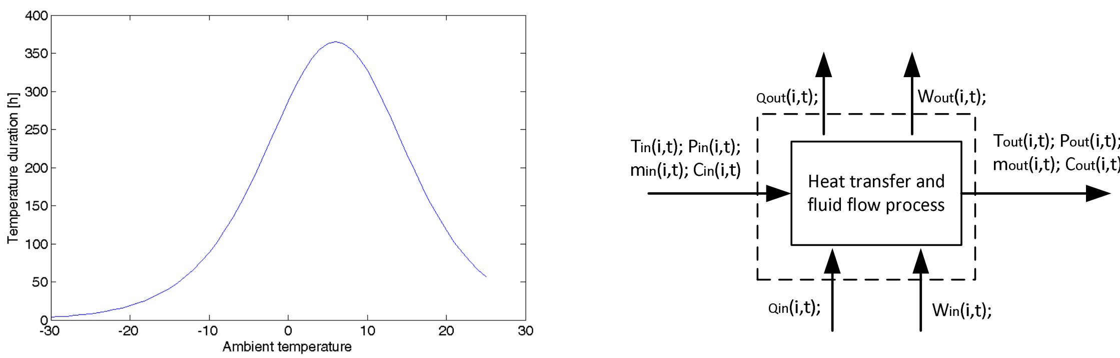

Fig. 2. Density function (on the left) and model of heat transfer and fluid flow process (on the right)

The proposed density function of temperature distribution can be expressed by functional dependence given in (Martinaitis *et al.* 2010).

Heat transfer and fluid flow process

In order to express thermodynamic performance indicators expressing qualities' perspective, primary process variables should be known. Mathematical models expressing the change of temperatures and pressures in flows across the process in the system or components should be used. It is important to used verified models or calculation procedures in order to get valid results.

Figure 2 also illustrates typical model, which summarizes main input and output parameters required for thermodynamic performance calculations. Primary variables – temperature and pressure should be known for each ingoing and outgoing flow (with mass and specific heat capacity) for every time period used in calculations. Additional variables like heat flux or thermodynamic work should be included for specific cases. Where T is temperature of the flow; P is pressure of incoming flow; m is mass flow; C is thermal capacity of flow; Q is heat flow; W is thermodynamic work. Indexes: in defines incoming flow, out defines outgoing flow. All these parameters are calculated for i-th boundary condition and time step "t".

Thermodynamic performance indicators

According to the engineering thermodynamics discipline or other disciplines focused on efficiency, effectiveness expression uses overall input or required resources ratio with created valuable output or product. Exergy demand depends not only on changing heat demand related to temperature difference but it reflects increased value of energy when ambient (equal to reference state) moves away from supply temperature. Exergy efficiency is typically expressed as a ratio of output and input or alternative expression is derived to account for qualitied losses:

$$\eta_{II} = \frac{Ex_{out}}{Ex_{in}} = 1 - \frac{Ex_{dest}}{Ex_{in}}, \tag{1}$$

where: η_{II} is the second law efficiency of the process/component; Ex_{out} is exergy amount or flow outgoing from the process/component; Ex_{in} is exergy amount or flow incoming to process/component, Ex_{dest} is exergy destruction.

The processes at near-environmental conditions with a variable reference temperature (RT) should be solved without restrictions at the all-possible cases when RT appears below, above and across the operating temperatures of working fluids. For some specific cases, special calculation approaches should be used to get valid the second law efficiency laying in the range between 0 and 1, which satisfies the given laws:

– Exergy destruction is equal to 0 for ideal reversible process and could not be negative.
– For real processes exergy destruction is always > 0 due to competing heat transfer and fluid flow processes.

Only calculations following these requirements are valid and correct according to classical theory. Using these rules ensures correctness of following seasonal performance results.

Seasonal performance calculations

The effectiveness expressed for steady state flows illustrates how efficient the process is for the given moment. For equipment, operating in varying conditions across the finite time period (month, season, year), the efficiency could be expressed in the same manner as a ratio of overall output to required input. The sums of flows are counted across finite time period and used to express periodic efficiency. For some cases steady state period efficiencies are expressed for exact moment (or time step) of system or systems element operation. In order to agregate the efficiencies of each time step, an additional weighting is required because average efficiency is not equal to periodic efficiency:

$$SE = \frac{\sum(Ex_{out})}{\sum(Ex_{in})} \neq \bar{\eta}_{II}\,, \tag{2}$$

where: SE is the second law seasonal efficiency; $\bar{\eta}_{II}$. is the average (arithmetical mean) second law efficiency of process/component.

Periodic or seasonal efficiency (SE) could be expressed when at least two components are known, with three possible combinations:

– Input and Output flows for each time step over the period;
– Process efficiency and Inputs for each time step over the period;
– Process efficiency and Outputs for each time step over the period.

In order to get normalized and more comparable results, the second and third approaches are more usable for simulation purposes.

During the period, different duration of equal boundary conditions has variable weight for seasonal efficiency. If the second law efficiency is known at specific calculation step, in order to integrate individual value to SE parameter influence should be expressed as weight multiplier. By using this formulation the equality between overal output/input and agregated efficiencies becomes equal:

$$SE = \frac{\sum(Ex_{out})}{\sum(Ex_{in})} = \sum\left(\eta_{II(i)} \cdot C_i\right). \tag{3}$$

This weight factor expresses the demand distribution as a density function of specific boundary duration (time). Where C_i is correction weight coefficient, which is equal:

$$C_i = \frac{Ex_{in-i} \cdot g_i}{\sum(Ex_{in} \cdot g)} \quad \text{or} \quad C_i = \frac{Ex_{out-i} \cdot g_i}{\sum(Ex_{out} \cdot g)} \tag{4}$$

Weight factor g could be determined to reflect duration of calculation time period and could vary for each calculation period part or be neglected ($g = 1$) for the cases of constant time step. As this function reflects the ratio between product of exergy demand during the time step and overall exergy demand, extreme values could be used to identify conditions with the highest influence on seasonal performance. Knowing these specific conditions may help to aim for design solutions and priorities for system optimization. For calculation verification, it is important to highlight that sum of all weight factors C_i should be equal to 1. This is clearly proven because numerator should always be less than denominator and numerator sum of all C_i should be equal to denominator:

$$\sum C_i = \sum\left(\frac{Ex_{in-i} \cdot g_i}{\sum(Ex_{in} \cdot g)}\right) \equiv 1. \tag{5}$$

This verification procedure enables to ensure the validity of calculation and does not require additional calculation resources due operation with existing data without generating additional variables or parameters.

Output data

The seasonal efficiency value for the system or component helps to indicate the level of design effectiveness. For advanced analysis when designer aims to adjust the heat transfer and fluid flow process to reach higher seasonal performance, calculation components like step efficiencies and weight factors may give valuable information and help to prioritize the actions for specific steps with individual boundary conditions. Defined calculation procedure workflow is suitable for integrated approach when coupled heat transfer and fluid flow processes are explored in short time steps with dynamic simulation software tools.

Case study

Various amount of energy is consumed to supply fresh air of constant temperature. Different hardware configurations could be used for this function (Fig. 3). We assume that an examined device supplies the air at constant 20 °C temperature. This helps to express amounts of supplied exergy required to satisfy this function for different options.

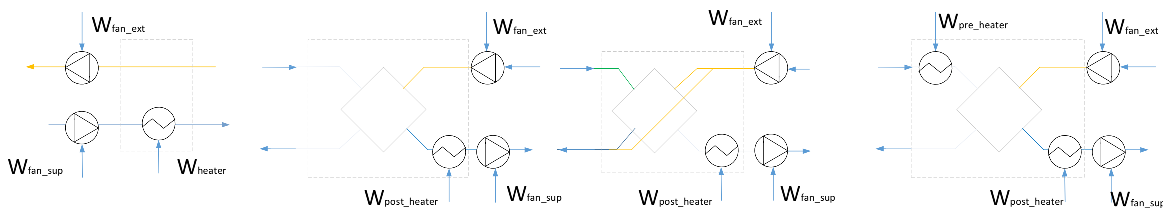

Fig. 3. Calculation schemes of ventilation systems (from left to right) – direct heating, with heat recovery (HR), with heat recover defrosted via by-pass, with heat recovery and pre-heating off supply air

As a summary of examined options, amount of required energy could be seen as a function dependent on ambient temperature and density functions of exergy supply. Direct supply air heating without HR and HR without frost formation illustrates the limiting bounds in which real system parameters should fit.

Efficiency of given process is expressed by following expression:

$$\eta_{II} = \frac{Ex_{out}}{Ex_{in}} = \frac{m_{\sup} k_{\sup}}{m_{ext} k_{ext} + W_{in}}, \tag{6}$$

where: W is electricity input; m is mass flow rate of air across the supply (subscript – *sup*) and extract (subscript – *ext*) channels; k is coenthalpy (or specific flow exergy) calculated according to formula (Martinaitis *et al.* 2016).

There is no frost formation on hot side of HR exchanger for the ideal case. In real devices due to low temperature of heat exchanger plate and humidity condensation on it, frost formates. To maintain continuous supply of air, defrosting periods are required. During these periods, frost is removed by removing cold flow (redirecting it to by-pass) and defrosting is organized by using heat from ventilation extract. Frosting effects in HR device start when exchanger plate temperature drops below 0 ºC and dew point of extract air flow is reached. Plate temperature could be calculated according to method given by Liu *et al.* (2016). The fraction of operation time required to defrost the ice is determined by method given by Januševičius *et al.* (2016). In general, frost formation start could be viewed as a curve from which frost factor surface starts to incline. Inclination intensity is highly dependent on heat transfer surface area due to influence on plate temperatures. Frost formation function expressing defrosts operational time fraction could be summarized as a surface function shown in Figure 4.

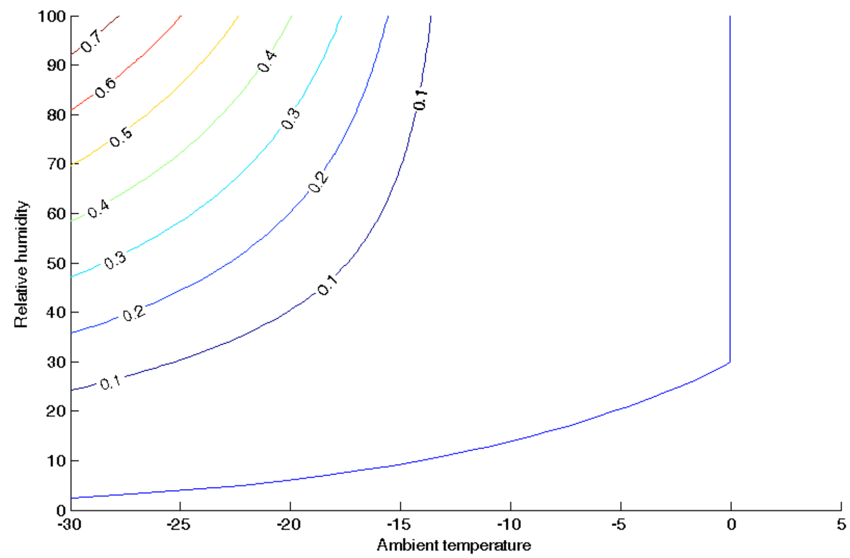

Fig. 4. Frost formation function (FF)

Different strategies of air heating and HR lead to various energy consumption dependencies related to ambient temperature. Alternative solution for frost formation prevention used in small ventilation units is supply air pre-heating. Typically, additional heaters are used to increase supply temperature above freezing point and ensure undisturbed continuous and constant air supply.

From sustainability perspective, more sustainable system is the one, which requests the lowest amount of resources in terms of quality and quantity. For this purpose, exergy efficiency is used. Application of previously explained mathematical model gives us opportunity to assess the seasonal efficiency of process in the system. The seasonal efficiency summarizes time-series data and creates straightforward possibility to compare values in clearly understandable way. Exergy efficiency of the options is summarized in Figure 5. It can be seen that the highest consumption has the lowest efficiency. At this study heat source was powered by electricity – pure exergy, the tendencies may change if low exergy source would be selected.

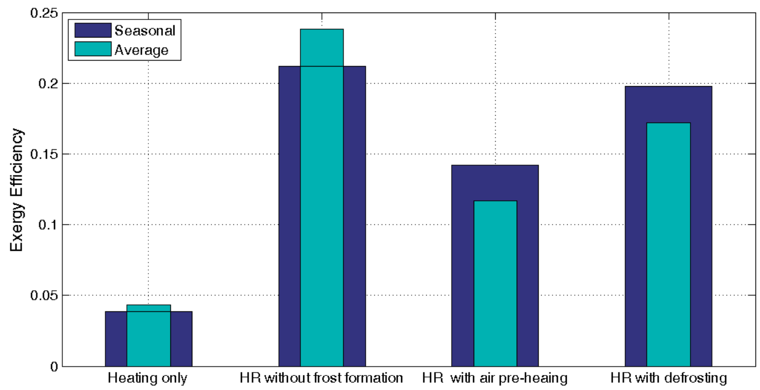

Fig. 5. Seasonal performance calculation results compared to average efficiency

Structure of seasonal performance allows decomposing efficiency parameters for each time step and weight factor. The weight factor in other hand clearly indicates period when there is the highest exergy consumption intensity. This period (time step) could have higher attention due to relative high impact to final result in comparison to others. If the results are viewed as combination of weight factor and exergy efficiency, additional perspective could be added illustrating magnitude of weigh, which highlights where the performance of process at thr given step has the highest influence on seasonal performance factor. This chart also may serve as comparison field of different selection options – the one with the greatest efficiency and the lowest maximum value should be the most sustainable option. The wideness of parameter spread brings better understanding how the system is dependent on examined variable and how sensitive to it the process is. Direct heating case has variation of exergy efficiency in range [0; 0.0929] and weight factor ranges in interval [0; 0.0458] as for all other cases. These values enables to identify operational extremes and aim the design decisions for operation point equal or close to the maximum weight factor. This prioritization strategy aims the focus for conditions having the highest influence on seasonal performance. Seasonal efficiency is 12.62% lower than average efficiency.

When the heat recover operates without frost formation, efficiency varies in the widest range [0; 0.512]. The wide variation enables to identify that it is important to explore all operational range in order to identify improvement potential and explore limitations of system arrangement. As this is an ideal case without frost formation, the result obtained of this case is used for comparison with following cases using implementations to avoid frost formation. This equality of difference to direct heating case may be explained by similar weight factor distribution form (see Fig. 6).

When supply air pre-heating is used to get rid of frost accumulated in heat exchanger, efficiency varies in range of [0; 0.209]. The distribution of weight factor is different due to mixed operation in normal heat recovery mode (until frost formation) and period when pre-heating device before heat recovery operates. This complex operation gives the highest deviation between seasonal efficiency and average efficiency – 17.79% higher than average. Removal of frost decreases seasonal efficiency from 0.212 to 0.142 and it is 32.78% difference due to frost formation in comparison to the ideal case.

Other option to defrost – the heat exchanger via warm extract air is more effective than supply air pre-heating and has efficiency variation in range [0; 0.319]. This leads to seasonal efficiency equal to 0.197, which is 13.21% higher than average efficiency (equal to 0.172) and has lower reduction due to frost formation – 6.52%. These results enable to state that this strategy is more efficient than supply air pre-heating from exergy efficiency point of view with given assumptions.

This case study highlights the differences between ventilation strategies used to ensure indoor air quality. Obtained results allow to summarize and state the following:

- Average efficiency is not suitable to express the seasonal performance of device due to discrepancy from seasonal quantity. Difference between those quantities may differ depending on case specific behaviour.

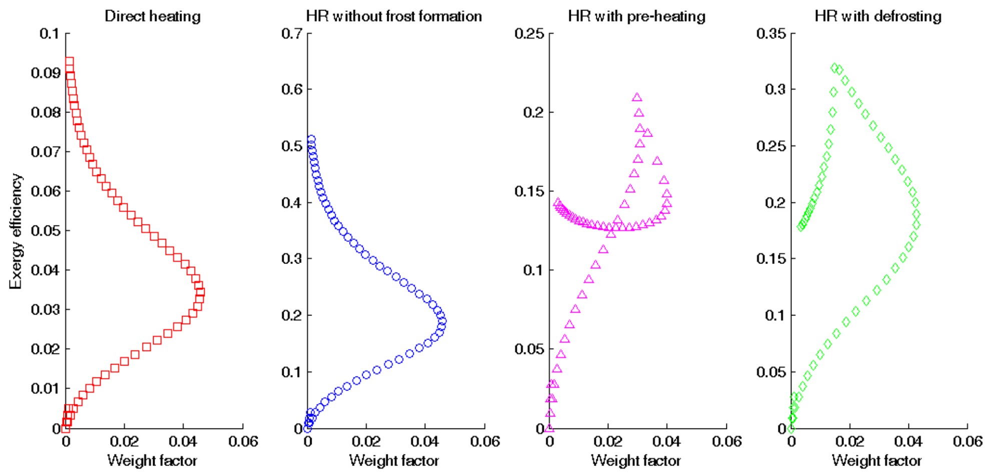

Fig. 6. Efficiency vs weight factor

- Driving factor influencing the difference between seasonal efficiency and average efficiency is weight factor and its distribution. Deviation from negative 12.62% to positive 17.79% (range of 30.42%) illustrates that average efficiency is not suitable for seasonal performance prediction.
- Seasonal efficiency is combined from exergy efficiencies, which vary in wide range of values across the year; the highest influence for this quantity has operation points with combination of the longest duration and the highest exergy input. This combination highlights condition when heat transfer and fluid flow process must be adjusted in order to increase the seasonal efficiency.
- Frost formation has influence on seasonal efficiency. In comparison to ideal case when frosting does not occur, strategies to remove frosting reduce efficiency – performance decreases by 6.52% when defrosting strategy is used and by 32.78% when supply air is pre-heated in order to avoid frost formation.

The case study used to demonstrate one of the possible applications of calculation workflow. The algorithm was tested on bin method based calculation created in MATLAB environment.

Conclusions

The calculation procedure of seasonal efficiency for variable reference conditions is presented and demonstrated. Case study of ventilation system is used to illustrate possible application of the presented algorithm.

Knowledge about defined procedures unlocks the possibility to fill up the implementation gap for building system engineering practice where seasonal performance parameters are widely used to express efficiency. The prepared algorithm allows to:

- Ensure consistency and process quality when expressing seasonal efficiency of the thermodynamic system or its components.
- Explore all operational range of the system in order to calculate efficiency and uncover the variation range of efficiency coefficient. It connects the efficiency with specific operation conditions – this holistic perspective allows going through the operation conditions and enables to identify efficiency peaks and decreases.
- Show conditions with the highest influence on seasonal efficiency. It is highlighted by the highest weight factor, which identifies target condition for the system performance improvement and optimization in order to increase seasonal performance.

Combined calculation procedure was implemented using MATLAB code and could be easily transferred to other calculation environment due to simple and straight forward logic of workflow. It could be used without limitations in quasy-steady state bin based methods (as demonstrated) and in transient (or quasi-steady state) simulations. Verification and debugging of calculations are simple and do not require high additional computational resources.

The presented framework fills the gap in lack of systematic expression of seasonal thermodynamic efficiency and suggests the process for calculation procedures workflow. Application and integration with other calculation and simulation methods will be done in future work. Exploration of seasonal efficiency of other systems and components arrangement may bring additional valuable information for activities aiming to increase sustainability and improve energy performance of buildings.

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Disclosure statement

Authors declare that our article do not have any competing financial, professional, or personal interests from other parties.

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