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The CLIMA 2019 HVAC World Congress was a success

Some great figures: 480 papers, 529 presentations, 11 keynote speeches, 19 workshops and a record attendance of 1056 participants. REHVA congratulates the Romanian organisers (AIIR and UTCB) with this successful outcome and their great hospitality. This REHVA Journal issue reports on several highlighted papers, the winners of student competitions, workshops and courses.

JAAP HOGELING
Editor-in-Chief
REHVA Journal

For those reaching out for our next CLIMA 2022 Congress: REHVA accepted the offer of the Netherlands association TVVL to organise this CLIMA 2022 (May 15-18, 2022). This will be for the first time in the Netherlands where REHVA has been founded. The location will be the city of Rotterdam.

The different selected papers are reflecting the different themes covered at CLIMA 2019. Several of our selected articles couldn't be included and will be published in our next issue due to the limited space.

On the Energy Building standards, a paper explaining the need for the use of hourly calculation procedures to achieve a level playing field for all energy saving technologies and explaining at the same time that this hourly procedure doesn't need more effort or input data if applied wisely.

A parametric study indicating that a perforated acoustic ceiling with integrated cooling and diffuse ventilation will increase heat transfer by 30-45% compared to the standard cooled ceiling panels.

Energy and Exergy: a really clear overview paper explaining the fundamentals in a understandable way.

Several papers prepared by students where highly appreciated and are of high quality. No surprise as they were awarded as winners of the World student, REHVA student and Daikin poster competition. Their papers are included in this issue.

Finally a Canadian case study which was presented earlier at the AIVC conference last year. A very interesting paper on the use of passive earth tube technology to save energy and enhance IEQ at the same time.

Finally the REHVA News section includes a lot of information on the CLIMA event and the activities and new developments at REHVA board level. ■

The new EN ISO 52000 family of standards to assess the energy performance of buildings put in practice

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Abstract

The set of Energy Performance of Buildings (EPB) standards, developed under a mandate from the European Commission to support the EPBD, has been published in summer 2017. This set of standards enables to assess the overall energy performance of a building. Several key EPB standards are available at global level (the EN ISO 52000 family of standards), while others are for the moment only available at European level (CEN standards). The revised European Directive on the Energy Performance of Buildings (EPBD), published in June 2018, obliges the EU Member States to describe their national calculation methodology following the 'national annexes' of the so called 'overarching' EPB standards. This will force the Member States to explain where and why they deviate from these standards and will lead to an increased recognition and promotion of the set of EPB standards across Europe and beyond. This paper provides background information and tips on how to put the EN ISO 52000 family of standards into practice.

1 Introduction

The set of Energy Performance of Buildings (EPB) standards has been published in summer 2017. This set of standards enables to assess the overall energy performance of a building; in most cases, but not exclusively, by calculation. A number of key EPB standards are available at global level (the EN ISO 52000 family of standards), while others are for the moment only available at European level (CEN standards).

The revised European Energy Performance of Buildings Directive (EPBD:2018 [1]) requires (in Annex I):

> *"Member States shall describe their national calculation methodology following the national annexes of the overarching standards, namely ISO 52000-1, 52003-1, 52010-1, 52016-1, and 52018-1, developed under mandate M/480 given to the European Committee for Standardisation (CEN). This provision shall not constitute a legal codification of those standards."*

So, although the new EPBD does not force the Member States to apply the set of EPB standards, the obligation to describe the national calculation methodology following the national annexes of the overarching standards will push the Member States to explain where and why they deviate from these standards. This will lead to an increased recognition and promotion of the set of EPB standards across the Member States and beyond.

In the following, background information and tips are given on how to put the EN ISO 52000 family of standards into practice.

2 The set of EPB standards

2.1 Mandate from European Commission to support EPBD

The set of standards and accompanying technical reports on the energy performance of buildings (set of EPB standards) have been prepared under a mandate, given to CEN by the European Commission and the European Free Trade Association, to support the EPBD (Mandate M/480, 2011 – 2016) [2].

Figure 1 shows a simplified flow chart of the main modules or elements in the assessment of the energy performance of buildings. Each of these modules is covered by one or more EPB standards.

2.2 Overall consistency

As **Figure 1** illustrates, the input needed in one EPB standard is provided as output by another EPB standard and, eventually, by product data (e.g. component properties), project data (e.g. geometry) and boundary conditions (e.g. climatic data, conditions of use). Evidently, it is extremely important that overall consistency is secured and maintained in terms, definitions and symbols and in the overall approach.

The teams who were responsible for the development of the set of EPB standards collectively worked out a set of quality documents, rules and templates (with the basis formed by [3], [4]). These quality documents were immediately put into practice during the development of the standards and are, based on the experience, gradually (being) updated.

A complete overview of all EPB standards is given at the EPB Center website (www.epb.center, [5]). More background information can also be found in recent articles, e.g. in the REHVA Journal ([6], [7]).

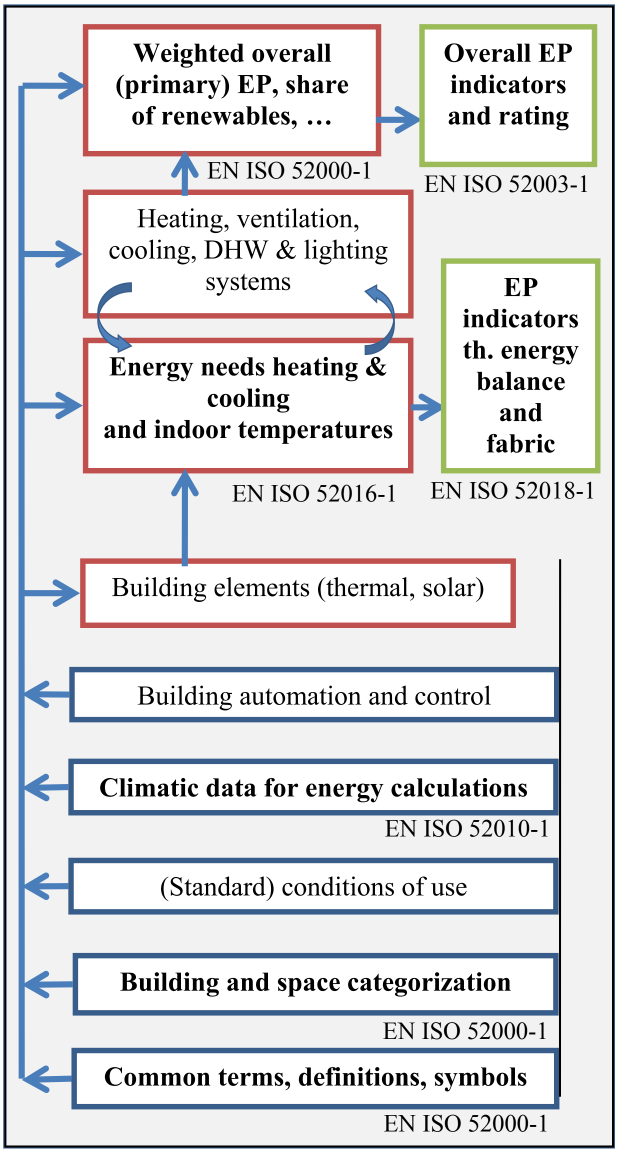

Figure 1. Flow chart of the set of EPB standards with position of the five 'overarching' EPB standards (in bold).

2.3 Holistic approach: instrument for policy targets and driver for innovation

In the past, energy performance requirements were set at component level – minimum thermal insulation levels and minimum efficiencies of products. This, however, leads to sub-optimal solutions and creates a barrier to the necessary technology transitions.

The set of EPB standards is based on the holistic or systemic approach: the assessment of the **overall** energy performance of a building. This implies that all types of building related energy uses (heating, lighting, cooling, air conditioning, ventilation) and outdoor climatic and local conditions, as well as indoor climate requirements are considered, including the sometimes complex and dynamic interactions between these various aspects.

This also implies that any combination of technologies can be used to reach the intended overall energy performance level, at the lowest cost. Due to this 'competition' between different technologies, the holistic approach is a key driver for technological innovation and change. Countries using the approach for several years – take, for instance, The Netherlands – have experienced large scale implementation and cost savings on a variety of new technologies.

The holistic approach is a key instrument to set and evaluate policy targets. Clear and consistent policy targets play an important role in driving innovation in the building sector ([8]).

2.4 The five 'Overarching standards mentioned in EPBD

The revised EPBD, quoted in the Introduction above, mentions explicitly five so called 'overarching' standards:

- EN ISO 52000-1 [9],
- EN ISO 52003-1 [10],
- EN ISO 52010-1 [11],
- EN ISO 52016-1 [12], and
- EN ISO 52018-1 [13].

Figure 1 (roughly) shows which elements are covered by these standards (**bold** and numbered). These five 'overarching' EPB standards have in common that each of them describes an important step in the assessment of the energy performance of building.

It is very fortunate that these five EPB standards are also available as ISO standards, which creates a strong basis for the roll-out of the other (CEN) EPB standards at worldwide level as well [14]. Harmonization of EPB assessment methodologies at global level will strengthen innovation on EPB solutions and products.

3. Supporting documents and tools

3.1 Accompanying Technical Reports

Each EPB standard needs to be as concise and unambiguous as possible: fit to be implemented or referenced in national or regional building codes. For that reason, each EPB standard contains purely normative procedures, with only brief notes (not part of the normative text) where unavoidable.

However, there would be a risk that the purpose and limitations of the EPB standards would be misunderstood, if the background and context to their contents – and the thinking behind them – would not be explained in some detail to readers of the standards. Therefore, each EPB standard (or sometimes a cluster of EPB standards) is accompanied by an (informative) technical report in which such kind of information is made available (including calculation examples), to properly understand, apply and nationally or regionally implement the EPB standards.

3.2 Accompanying spreadsheets

One of the instruments to check the necessary overall consistency and coherence, in terminology, approach, input/output relations and formats, was the preparation of a spreadsheet for each EPB calculation standard. These spreadsheets, prepared on the basis of a common template, intend to demonstrate the correctness of the EPB calculation procedures and to enable a check of the list of input and output variables; in particular with respect to the interconnections between the standards, as mentioned above.

Because each spreadsheet was developed in parallel with the corresponding EPB standard, and was used to detect omissions in the standard and mismatches in input-output relations between the EPB standards, the most recently available version of the spreadsheet in many cases reflects a draft version of the standard (from 2014 or 2015) and has not or not yet been updated to the level of the published version (summer 2017) of the standard. These spreadsheets can be downloaded from the EPB Center website.

3.3 More to come…

In the context of a Service Contract [17] with the European Commission, the EPB Center intends to upgrade the spreadsheets of the most important standards during 2019 and 2020 and prepare case studies. See more under section 6 of this paper.

4 National Annexes

4.1 National choices to tailor the EPB standards to the national situation

The set of EPB standards offers an internationally agreed set of methods to assess the energy performance of buildings in a harmonized, modular and transparent way. At the same time, the individual countries can tailor the standards to their national building regulations, building tradition, technology infrastructure and climate. They thus combine the benefits of an internationally harmonized approach with specific national or regional features.

For this purpose, each EPB standard has an "Annex A": a *template* providing choices:

- choices between specific methods (e.g. simple or more detailed),
- including choices of references to other EPB or national standards for specific elements of the calculation, and
- choices of input data; these covers technical, policy related or climate related data.

The choices according to the Annex A template, made by the Member States and/or National Standards Bodies, are to be laid down in National Datasheets (e.g. annexed to the building code) or in National Annexes to these standards (referenced by the building code). In any case, each of these National Datasheets or National Annexes shall comply with the template of Annex A of the corresponding EPB standard.

In the context of the afore mentioned Service Contract with the European Commission [17], the EPB Center will collect and distribute examples and tips on the preparation of National Annexes. And also provide support on how to use the template of Annex A to report a (deviating) national methodology, as requested in Annex I of the revised EPBD [1], as quoted in the Introduction above.

4.2 Examples of the types of choices

A rough impression of the types of choices provided in the EPB standards can be obtained by looking at the main types of choices provided in the five 'overarching' EPB standards:

EN ISO 52000-1 (On the general EPB framework, [9]): About 30 tables with choices. For instance, on:

- **Physical** parameters (e.g. *gross calorific values*).
- Differentiation into different **building and space categories** (distinction between -for example- single family house, apartment building, office, hospital, education, assembly, sport, restaurant, hotel, holiday home, etc.; or e.g. a less refined differentiation).

  Plus, related issues such as: which categories are kept outside the **boundaries of the EPB-assessment** (for instance industrial sites, workshops, indoor parking; or any other choice of building or space categories).

  This categorization has a strong influence on the EP assessment: each category is linked to an assumed set of **conditions of use** (temperature, IAQ, DHW, lighting, …). By the way, the (assumed, standard) settings for these *conditions of use* are also determined nationally, in the relevant other EPB standards; see **Figure 1**.

  Via these *conditions of use*, the categorization has also a strong effect on the need to **partition the building** into different zones or sections for the calculation: e.g. spaces with different temperature settings may require separate calculation (separate thermal zones). This, in turn, leads to more input data (e.g. the floor, façade and window area per zone).

  Moreover, the more refined the categorization and the distinction in *conditions of use*, the more likely it is that the **minimum EP requirements** need to be refined (see also EN ISO 52003-1 below).

  But on the other hand, if the categorization is less refined, the predicted energy performance may be less close to the energy performance in practice.
- Energy performance **boundaries** (e.g. whether *PV surplus to the grid* is rewarded in the energy performance or not. Or whether "*distant*" and/or "*nearby*" renewable energy sources (with –national- specification of "*nearby*") are included in the *renewable energy contribution* or not.
- **Policy factors** (e.g. Primary energy factors). The choice of PE factors for electricity versus e.g. gas and oil will have a direct effect on the competitiveness of technologies that use the one or the other energy carrier.

EN ISO 52003-1 (On EP indicators, requirements and ratings, [10]):

- Standardized tables for reporting in a structured and transparent manner the choices that are to be made with respect to overall EPB requirements. For example: choice on the numerical EP indicator and the EP rating method (classes).

  The tables are non-restrictive, thus allowing for full regulatory flexibility. The aim is to offer choices together with the rational (motivation, pro or con) behind each choice:

  – To offer possibility for harmonization.
  – To bring in more transparency (comparison, exchange of best practices).

  The EPB procedures are very refined (many standards, dealing with all kind of details), so it would be unproductive if the energy performance requirements are formulated in a (too) simple crude way, which would be not cost optimal or cost effective for many buildings …

EN ISO 52010-1 (On conversion of climatic data for energy calculations, [11]):

- The weather station and climatic data set.
- Method to estimate direct solar (beam) irradiance if not available from weather station (needed for conversion to tilted and vertical planes and for calculating solar shading by external obstacles).
- Solar reflectivity of the ground (fixed value or e.g. function of snow coverage).
- (Default) solar shading from surroundings (horizon) included or not.

EN ISO 52016-1 (On the energy need for heating and cooling and indoor temperatures, [12]):

- Main choice: hourly and/or monthly method (choice may differ per category of buildings).
- Second main choice: specific rules for thermal zoning (in 10 steps); each step can be modified or replaced.
- Other typical national choices:
  – Options of thermally unconditioned zone types and default values for simplifications.
  – Choice between calculations with thermally coupled or uncoupled thermal zones.
  – Details such as: convective fractions, solar absorption coefficient of external opaque surfaces, view factor to the sky, etc.
  – Rules for operation of solar shading devices.
  – Choices between options and methods for calculation of shading by external objects.
- Additionally, for the hourly method only:
  – Choice between a few specifically allowed alternative choices in modelling (without compromising reproducibility and transparency).
- Additionally, for the monthly method only:
  – The values of various correlation factors (gain utilization factors, intermittency, …
  – The parameters for effect of movable shading devices, simplified (fixed) shading calculation, …

EN ISO 52018-1 (On partial EP indicators to building fabric and building thermal balance, [13]):

- Similar as for EN ISO 52003-1. For instance, choices to set requirements on partial energy performance features (with optional choices on further details). Such as *yes or no* minimum requirements on one or more of the following aspects:
  – Summer thermal comfort
  – Winter thermal comfort
  – Energy needs for heating and/or cooling (with further specification of assumed ventilation, etc.)
  – Thermal insulation of envelope and/or individual elements
  – Thermal bridges
  – Windows energy performance
  – Air tightness
  – Solar control

5 Hourly calculation procedures

5.1 Overarching EPB standard

The overarching EPB standard (EN ISO 52000-1, [9]) lists different options for the time interval for the calculation of the energy performance: hourly, monthly, seasonal, yearly and bin. In most countries a choice is made between monthly and hourly calculation procedures.

Overall consistency is needed in the choice of time interval for the successive modules/elements in the calculation (see **Figure 1**). This, however, does not mean that the choice for an hourly time interval implies that every calculation element (such as the *U*-value of constructions) is assumed to be varying on an hourly basis.

5.2 Balanced accuracy

For use in the context of building regulations it is essential that the procedures to calculate the energy performance of a building are not only **accurate**, but also **robust** (applicable to a wide range of cases). It is also essential that they are **reproducible** (unambiguous) as well as **transparent** and **verifiable** (e.g. for municipalities, to check compliance with national or regional minimum energy performance requirements) and **applicable/affordable** (e.g. for inspectors, assessing the energy performance assessment of an existing building).

The accuracy of the model should always be in proportion with the limits and uncertainty in input data and with the required robustness and reproducibility of the method, but at the same time the calculation should provide a sufficient and realistic appreciation of the wide variety of available energy saving technologies: a balanced accuracy.

This concept was introduced more than a decade ago by B. Poel ([16]). It implies that the most accurate, complete and state of the art method is not necessarily the most appropriate method for a specific application. This is in particular true for calculations in the context of building regulations.

5.3 Low energy use: strong dynamic effects

On the other hand, many technologies, in particular for low energy buildings aiming to meet today's energy performance requirements, are strongly and dynamically interacting with the hourly and daily variations in weather and operation (solar blinds, thermostats, needs, occupation, accumulation, mechanical ventilation, night time -free cooling- ventilation, weekend operation, heat pump, solar panels, etc.). This has a strong effect on the calculated energy performance.

In the past, the dynamic effects had less prominent effects (**Figure 2**, from [12]). But in low energy buildings these effects can become very large (**Figure 3**). This strongly influences the pro's and con's of the monthly versus hourly calculation method.

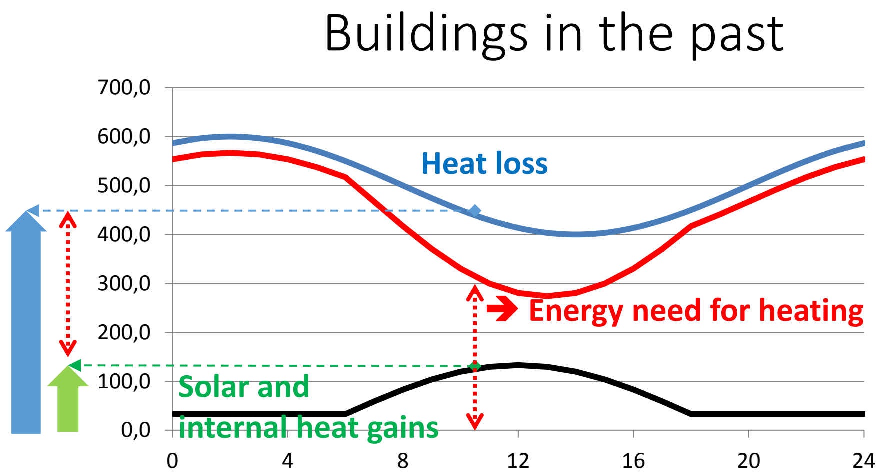

Figure 2. Illustration of the thermal balance in case of buildings in the past: the difference between the heat losses and the heat gains (~ the energy need for heating) is large and much less fluctuating as in low energy buildings (compare **Figure 3**).

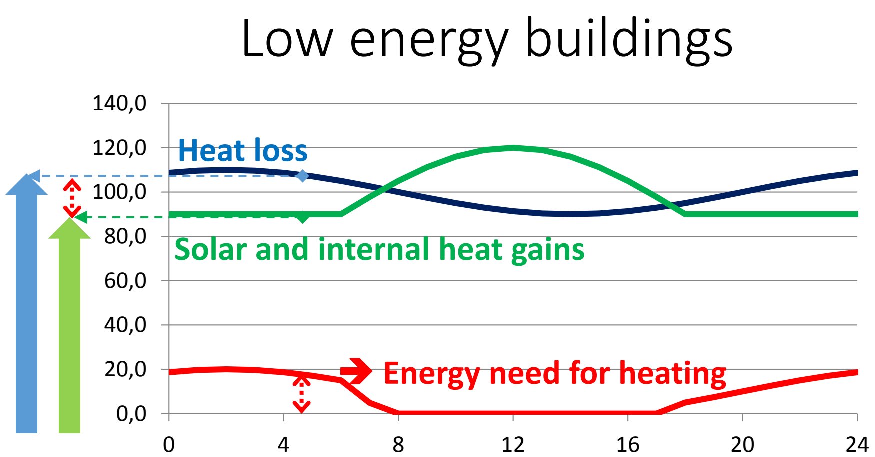

Figure 3. Illustration of the thermal balance in case of low energy buildings: the difference between the heat losses and the heat gains (~ the energy need for heating) is small and more fluctuating.

5.4 Monthly versus hourly method in EN ISO 52016-1

5.4.1 EN ISO 52016-1:2017: successor of EN ISO 13790:2008

The choice between hourly or monthly calculation procedures is most prominently visible in the calculation of the energy needs for heating and cooling and indoor temperatures: EN ISO 52016-1 from 2017 ([12]). This standard superseded the well-known EN ISO 13790 from 2008. Like its predecessor, EN ISO 52016-1 contains, side by side, both a monthly and an hourly calculation method.

5.4.2 Monthly method in EN ISO 52016-1

The monthly calculation method in EN ISO 52016-1 has not been fundamentally changed compared to EN ISO 13790:2008. It contains correction or adjustment factors to account, in a kind of statistical way, for the dynamic effects that are mentioned in 5.3 above. These factors are usually pre-calculated, based on a large series of building simulations with e.g. variations of daily weather, conditions of use and building design.

However, for low energy buildings and buildings with dynamically (inter-)acting technologies, the monthly method is no longer the simple transparent method that it used to be. Due to the necessity to introduce an increasing number of correction or adjustment factors, the original transparency and robustness of the monthly method has been lost. The more of the above-mentioned dynamic technologies and processes are included in the monthly calculation method, the less transparent the monthly calculation method becomes, and the more an hourly method becomes the transparent alternative.

5.4.3 Hourly method in EN ISO 52016-1

An hourly calculation method can directly calculate the effect of dynamic interactions and, consequently, it does not need the series of correction factors that the monthly method requires. But the challenge for an hourly method is to avoid the need for too many input data from the user. More input data would introduce more uncertainties that could easily lead to a loss of overall accuracy, or lead to significantly higher assessment costs.

The hourly calculation method in EN ISO 52016-1 has been improved drastically compared to its predecessor (EN ISO 13790:2008) in two ways:

(1) EN ISO 13790:2008 contained a very simple, aggregated (few lumped parameter nodes) model in which all building elements surrounding a thermal zone (except windows) were aggregated to a single overall thermal transmittance, including such different elements as roofs, walls and ground floor... This is a loss of available information (*U*-value, size, orientation and mass of each building element) and –consequently- to problems in e.g. the estimation of the effective thermal mass and effective solar energy gains.

In contrast to this, EN ISO 52016-1 contains a full dynamic method, in which the *U*-value, size, orientation and mass of each building element are used directly, without aggregation.

(2) At the same time, the details of this hourly method in EN ISO 52016-1 have been tailored to the goal: one of the main accomplishments of this new hourly method is that the method does not require extra input from the user compared to the monthly calculation method.

In short: the hourly and the monthly method in EN ISO 52016-1 are closely linked: they have been developed side by side and they use, all together, the same input data and assumptions.

5.4.4 Hourly method in EN ISO 52016-1 to derive monthly correlation factors

Consequently, the hourly method is also very well suited for the derivation or validation of the correction and correlation factors of the monthly method. For instance, by carrying out many hourly calculations runs for a specific range of building categories, with a variety of building types and designs. This is illustrated by the flow chart in **Figure 4**.

Normally, another dynamic simulation tool is needed for such purpose; with therefore that differences in assumed conditions and differences in model approaches lead to a lot of noise in the derivation/validation of the correction or correlation factors. This is eliminated by comparing the side by side developed hourly and monthly method from EN ISO 52016-1.

5.4.5 Link with EN ISO 52010-1

One of the additional causes for the kind of "noise" mentioned above is the amount of solar irradiation at vertical and tilted planes, calculated on the basis of the measured solar irradiation at horizontal plane. This is an important input for the calculation of energy needs and indoor temperatures, especially in case of low energy buildings.

The main internationally available building simulation tools use quite similar but yet different algorithms for this conversion. This is probably one of the reasons why in the so called BESTEST cases ([18]) discrepancies between building simulation tools occur on the calculation of energy needs for heating and cooling and indoor temperatures. With the introduction of EN ISO 52010-1 [11], this algorithm has now been harmonized which eliminates this additional noise. This is explained in more detail in 7.2.1 of the Technical Report accompanying EN ISO 52016-1 [19].

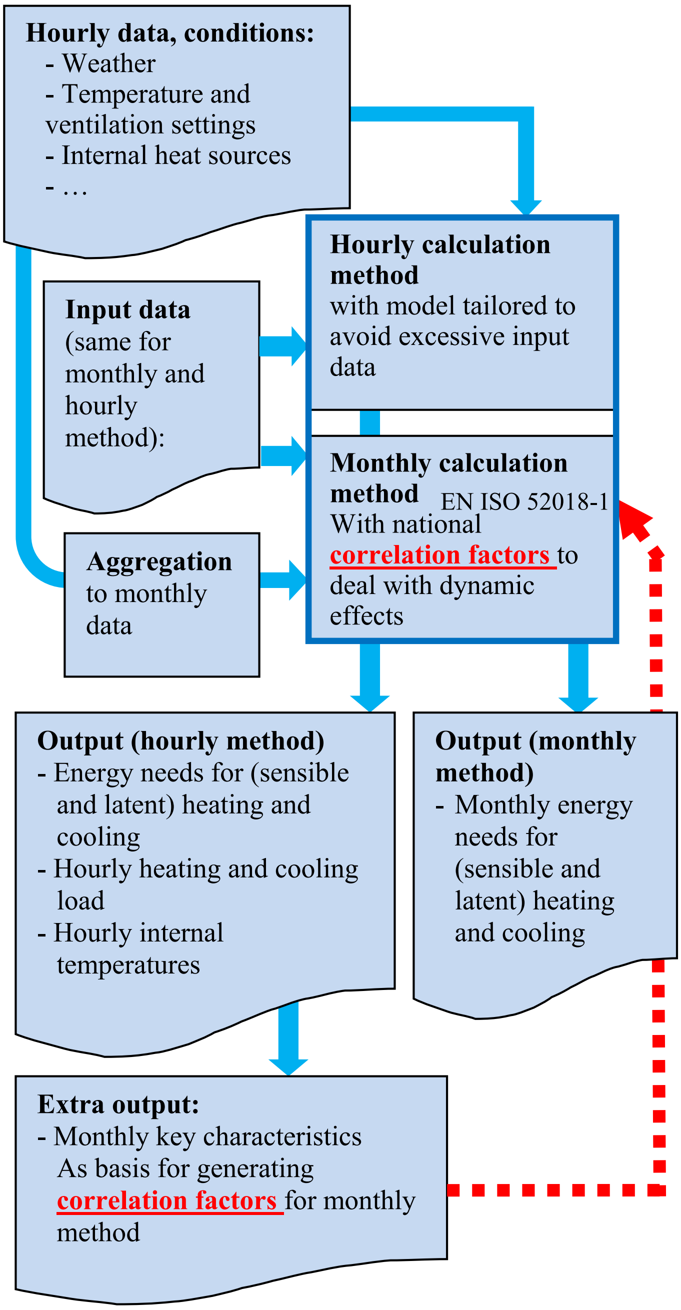

Figure 4. EN ISO 52016-1: links between the hourly and the monthly method provided in this standard.

5.5 Smart readiness

One could easily defend that the assessment of the smart readiness of a building, one of the new concepts in the revised EPBD [1], requires hourly (or sub-hourly) calculation intervals. It is quite evident that in different buildings the same "smart" service or technical feature can result in different outcomes. According to the revised EPBD ([1]) the 'Smart Readiness Indicator' (SRI) should focus on the building's adaptation to user and grid needs. Only assessment of the performance of the building by calculation or measurement can provide a realistic quantification of the 'smart readiness'.

Evidently, a *monthly* calculation method lacks the possibility to reveal the potential to adapt to the user and grid needs. In fact, the use of monthly average data (e.g. monthly mean electricity surplus or shortage), intrinsically leads to over-optimistic results. The set of EPB standards offer the possibility for *hourly* calculations to provide meaningful results.

6 Service Contract with European Commission

The European Commission awarded a service contract (Sept.2018 – Sept. 2021) to a team led by ISSO ([17]), to support the uptake of the EPB standards. Examples of activities under this contract:

- Support to EU Member States and National Standardization Bodies that wish to complete the National Annexes of the EPB standards.
- Set up a public frequently asked questions database on filling in National Annexes, on practical application of the standards, etc.
- Preparation of practical case studies to support the use of standards and dissemination and development of calculation tools for individual standards.
- Set up of a large network of practitioners and support of the uptake of the EPB standards by organising regular hands-on workshops, training sessions, etc.

The EPB Center, founded by ISSO and REHVA, will be the communication platform to offer these services. More information will gradually become available at the website (www.epb.center). The web site also offers the possibility to provide feed-back, suggestions and questions on the set of EPB standards and their implementation.

7 Conclusions

With the publication of the set of EPB standards (2017) a powerful set of internationally harmonized assessment procedures on the energy performance of buildings has become available. These harmonized procedures offer flexibility to take into account the national or regional situation via so called national annexes or datasheets.

The EPB Center provides information and technical support for and collects feedback on the uptake of the set of EPB standards at national and regional levels.

This set of methods is a key instrument to set and evaluate the national and international policy targets and will play an important role in driving innovation in the construction sector. ■

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Radiant ceilings combined with diffuse ventilation

– a numerical parametric study of cooling performance

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Abstract

Focus on indoor comfort, energy savings and Near-Zero Energy Buildings (NZEB), and the focus on finding new approaches for heating, cooling and ventilation increases. Suspended radiant ceiling panels combined with diffuse ventilation offers a novel approach for integrating heating, cooling, ventilation and acoustics for high-performing NZEB buildings. This paper presents a numerical parametric study of a perforated suspended ceiling with embedded hydronic pipes where the ceiling perforations are used for diffuse ventilation. The investigations focus on the heat transfer coefficient from the ceiling to the room and from the ceiling to the plenum in cooling mode. A suspended gypsum ceiling with embedded pipes was investigated with and without ventilation. The investigations were carried out in the multi-physics simulation program COMSOL with different scenarios of pipe spacing, materials, dimensions, and surface heat transfer coefficients. The objective of the investigations was to identify several solutions for a ceiling panel that promises to combine heating, cooling, ventilation and acoustic performance for future NZEB buildings – in short HCVA ceiling panels. The investigations indicate a potential heat transfer increase from an HCVA panel of 30–45% compared to a stand-alone radiant ceiling. The increase is mainly due to the increased convective heat transfer in the plenum which cools the ventilation supply air before it enters the occupied zone.

1 Introduction

The international strive to achieve a comfortable indoor environment and increase productivity of building occupants while saving energy has led to increasing demands on novel approaches to heating, cooling and ventilation of buildings. One such novel approach is to combine hydronic radiant ceilings with diffuse ceiling ventilation.

Diffuse ceiling ventilation is characterized by using a large perforated surface to supply air to the room. This ventilation concept uses the void between the floor slab and the suspended acoustic ceiling, the so-called plenum, to create a positive pressure chamber that forces the air through the acoustic perforations and into the room. It allows for air to enter the room at significantly reduced inlet velocity, which seems to impact draught and noise positively [1]. It also simplifies the building process because air terminals and some of the ductwork installation can be omitted [2].

There are several types of hydronic radiant ceiling systems and they can be separated into three categories [3]:

1. Pipes embedded deep in the main structure (Thermally Active Building Systems, TABS)
2. Pipes isolated from the main structure (radiant surface systems)
3. Radiant heating and cooling panels (pipes suspended from the floor separation slab).

In this paper, the focus will be on the 3rd option – suspended radiant ceiling system with pipes embedded in the perforated acoustical ceiling panel and suspended from the slab. The radiant ceiling provides a large heat transferring surface in the room that allows heating and cooling to be supplied at temperatures that are close to the room comfort temperature.

The hydronic radiant ceiling in combination with diffuse ventilation is a promising option for merging heating, cooling, ventilation and acoustics services in one building component. Previous similar studies have mainly been on combinations with TABS system. One approach of combining TABS with diffuse ventilation was performed by Yu et al. and Zhang et al. [4], [5], but the heat transfer to the room is reduced significantly due to the acoustical perforated ceiling panels covering the TABS slab completely.

This has led to the investigation of embedding the pipes in the suspended ceiling, and to start quantifying the thermal performance: can the radiant ceiling provide heating and cooling for the plenum for pre-cooling/heating the ventilation air and for the room below to ensure indoor comfort. Experimental studies by Eriksen & Christiansen [7] and Onsberg & Eriksen [8] showed higher heat transfer from the radiant ceiling when combined with diffuse ventilation and Krusaa et al. [6] employed the principle in a simulation study that proved adequate indoor comfort and significant energy savings for different room types. However, more thorough investigation of the heat transfers from the ceiling need to be made to confirm the hypothesized superior thermal performance.

The objective of the present study was to numerically study a combined ceiling panel for heating, cooling, ventilation and acoustics – the HCVA panel – to disclose the expected cooling performance increase when the suspended radiant ceiling also acts as the air terminal device. The investigation is carried out as a parametric numerical study to help identify the most sensible parameters and understand their effect.

2 Methods

The thermal performance of the HCVA panel was simulated in the multi-physics numerical tool COMSOL version 5.3, using the 2D model environment with the physics for "Steady-state Heat Transfer in Solids".

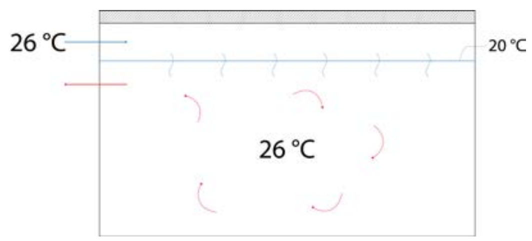

Figure 1. Reference room with the HCVA panel in a cooling scenario.

The radiant acoustical ceiling was a sandwich construction consisting of an aluminium heat distribution plate placed between two perforated gypsum tiles (600 x 600 mm), see **Figure 2** and **Figure 3**.

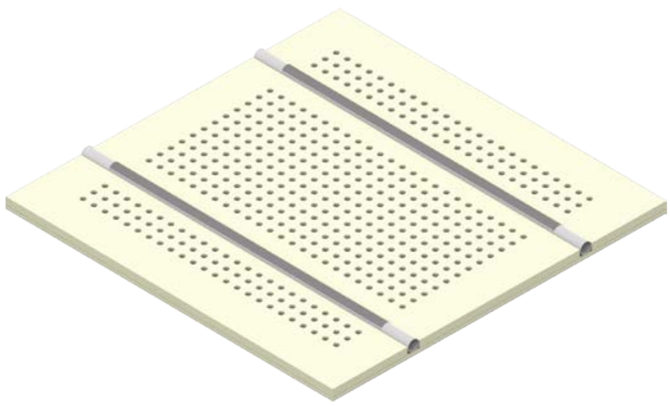

Figure 2. The reference radiant acoustical ceiling panel, depicted with slightly too large pipes.

2.1 Reference model

The reference model forms the basis from where the different scenarios have been tested. A cross-section of the reference model is depicted in **Figure 3**.

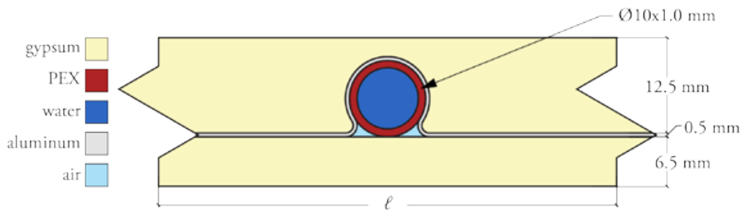

Figure 3. Cross-section of reference model.

The reference model had a c-c distance between the pipes (from centre to centre) of 300 mm. The material properties are listed in **Table 1**.

Table 1. Material properties.

Material	Thickness	Thermal conductivity
Gypsum	12.5 mm 6.5 mm	0.25 W/mK
Aluminium	0.5 mm	238 W/mK
PEX	Ø10 x 1 mm	0.35 W/mK

For the reference model without ventilation, the surface heat transfer coefficients from the ceiling to the plenum ($h_{s,p}$) and from the ceiling to the room ($h_{s,r}$) were calculated using the ASHRAE handbook [9] to be 6 W/m²K and 10 W/m²K [10], respectively, including both radiative and convective heat transfer. For all parametric studies, the air temperature was kept the same in both plenum (T_p) and room (T_r) at 26°C and a temperature of 22°C as a boundary for the water (T_w), i.e. cooling mode.

2.1.1 Preliminary research for heat transfer coefficient in plenum

Building simulation tools often uses fixed heat transfer coefficients for the enclosure surfaces, often ignoring airflow rate and inlet type. With the combined panel proposed in this paper, the upward surface heat transfer coefficient is of crucial importance to the total heat transfer. And the heat transfer coefficient varies with airflow rate and inlet type in the plenum as well as the temperature difference between supply air and mean plenum temperature.

Consequently, preliminary studies of the convective heat transfer coefficient was made in CFD by Eriksen & Christiansen [7] for heating and cooling scenarios. In order to qualify the results, we plotted them in relation to Spitler [11] and Fisher [12], who made studies of the convective heat transfer coefficients in an enclosure for different air change rates. Spitler and Fisher found that the relation was predominantly determined by the jet momentum J:

$$J = \frac{q_v \cdot v}{g \cdot V_{room}} \quad [-] \tag{1}$$

Where

g_v = air flow [m³/s]
v = velocity of supply air [m/s]
g = 9.82 [m/s²]
V_{room} = volume of room (plenum) [m³]

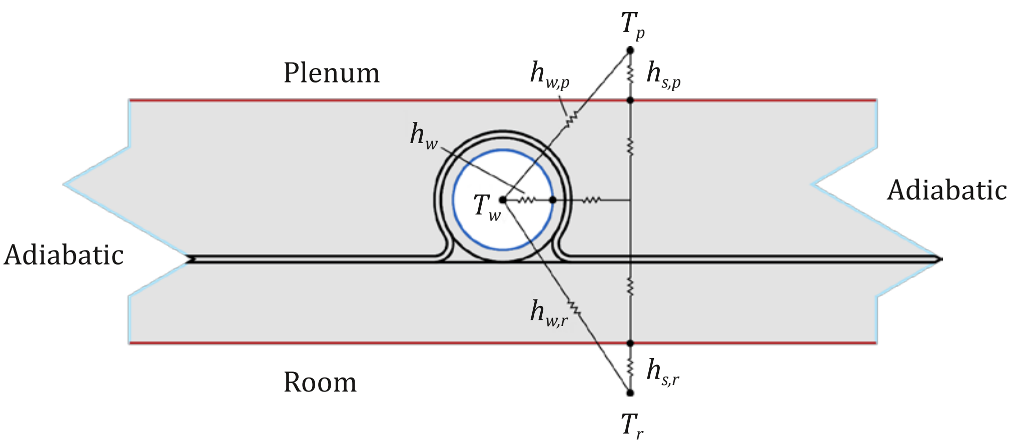

Figure 4. Boundary heat transfer and temperatures used for the calculations.

In **Figure 5** the results are plotted for the resulting jet momentum. Spitler found that the jet momentum correlation was valid for Ar < 0.3 which is the case for all parametric scenarios in this paper.

The results in **Figure 5** from Eriksen & Christiansen show that as buoyant flows become more predominant (low jet momentum) the convective heat transfer reduces. This effect is more pronounced for cooled floors due to stratification. Considering the advances in CFD, we use the calculated upward surface heat transfer coefficient $h_{s,p}$ from Eriksen & Christiansen. The values are shown in **Table 2**.

2.2 Parametric study

Table 3 lists the parametric investigations of the combined ceiling panel: the pipe distance, the aluminium thickness, insulation on top of the ceiling, and different surface heat transfer coefficients.

The pipe distance was tested for a c-c of 100, 150 and 300 mm to have as few pipes in the ceiling as possible for maintenance and costs reasons, but still have sufficient capacity for a low-energy building.

Table 2. Upward surface heat transfer coefficient $h_{s,p}$. Low and high diffuse ventilation rate correspond approx. to the hourly airchange in open plan office and meeting room.

Convective W/m²K	Radiant W/m²K	Total W/m²K	
0.5	5.5	6	Without diffuse ventilation [9]
3.5	5.5	9	Diffuse low rate ACH 3.1 [7]
6.5	5.5	12	Diffuse high rate ACH 6.7 [7]

Table 3. Scenarios in project. Reference case in bold.

Parameter	Values
Pipe distance	100 – 150 – **300** mm
Aluminium thickness	**0.5** – 0.7 – 1.0 mm
Insulation on top	**0** – 40 mm
Upward surface heat transfer coefficient	**6** – 9 – 12 W/m²K
Thermal conductivity: gypsum core	**0.25** – 0.52 W/mK

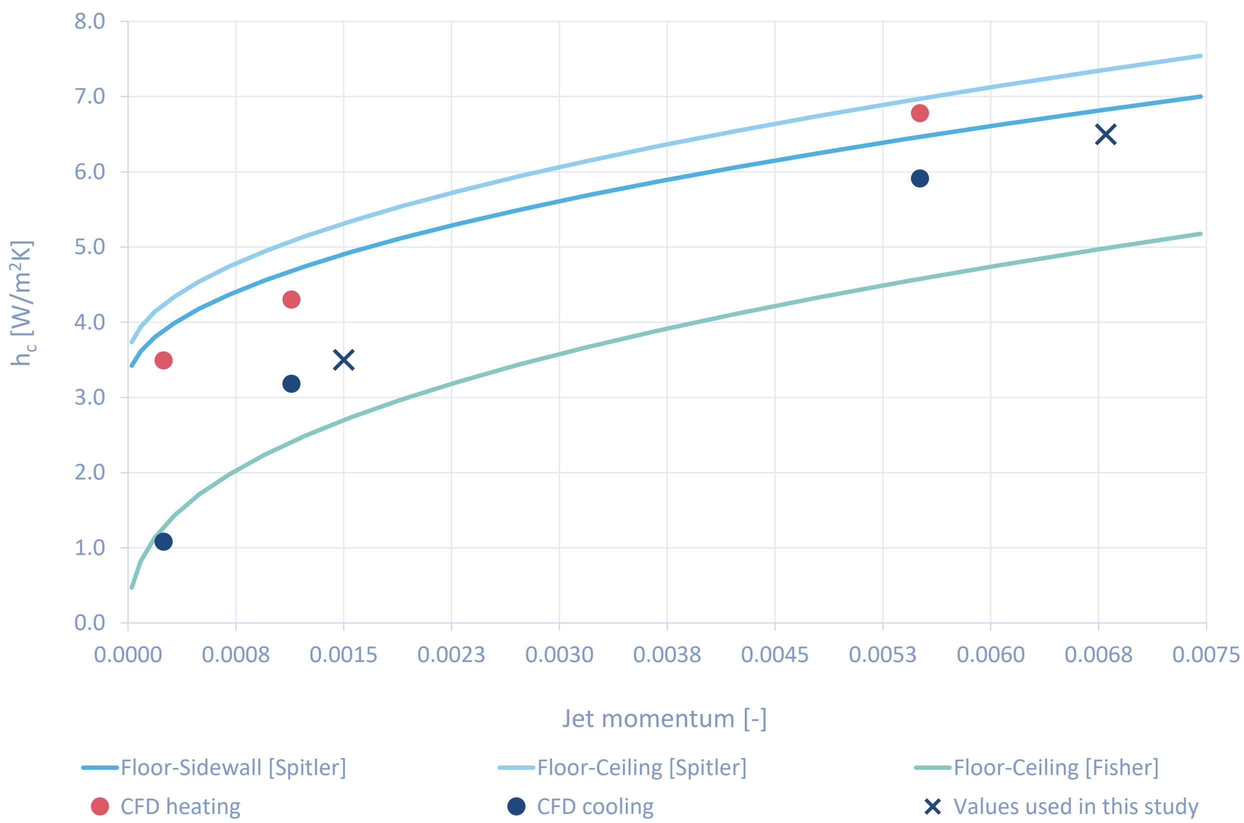

Figure 5. Heat transfer coefficient on floor for different inlet surfaces (sidewall jet and ceiling diffuser). Adapted from Fisher and Spitler (solid lines). CFD results for heated and cooled floor as dots (Eriksen and Christiansen, [7]).

The aluminium thickness of the heat distribution plate was changed to 0.7 mm and 1.0 mm, to quantify the impact of a thicker heat conducting layer.

The surface heat transfer coefficient was changed on top of the plate to mimic the effect of diffuse ceiling ventilation. The value was changed from 6 W/m^2K (stagnant air, no diffuse ventilation) to 9 W/m^2K and 12 W/m^2K which corresponds to approximate ventilation rates of an open plan office and a meeting room.

The influence of the insulation on top of the ceiling was tested because it is important to the acoustic properties of the ceiling panel. In the investigation 40 mm insulation (45 mW/m^2K) was placed on the top. The insulation thermal resistance and the upward surface resistance were lumped into one heat transfer coefficient of 1 W/m^2K.

Also, the effect of the gypsum core conductivity was tested, to quantify the impact of using a thermally high-conducting gypsum board with a blend of graphite (0.52 W/mK).

2.2.1 Impact of acoustical perforations.

The acoustical perforations of the ceiling panel are essential for both the acoustics and for the ventilation air to pass through. A standard heat distribution plate has no holes to let the air and sound pass through. Therefore, the heat distribution plate must be perforated in order to ensure the acoustical performance. However, the perforations have a negative impact on the heat transfer of the plate. Consequently 5 different patterns were also tested, **Figure 6**.

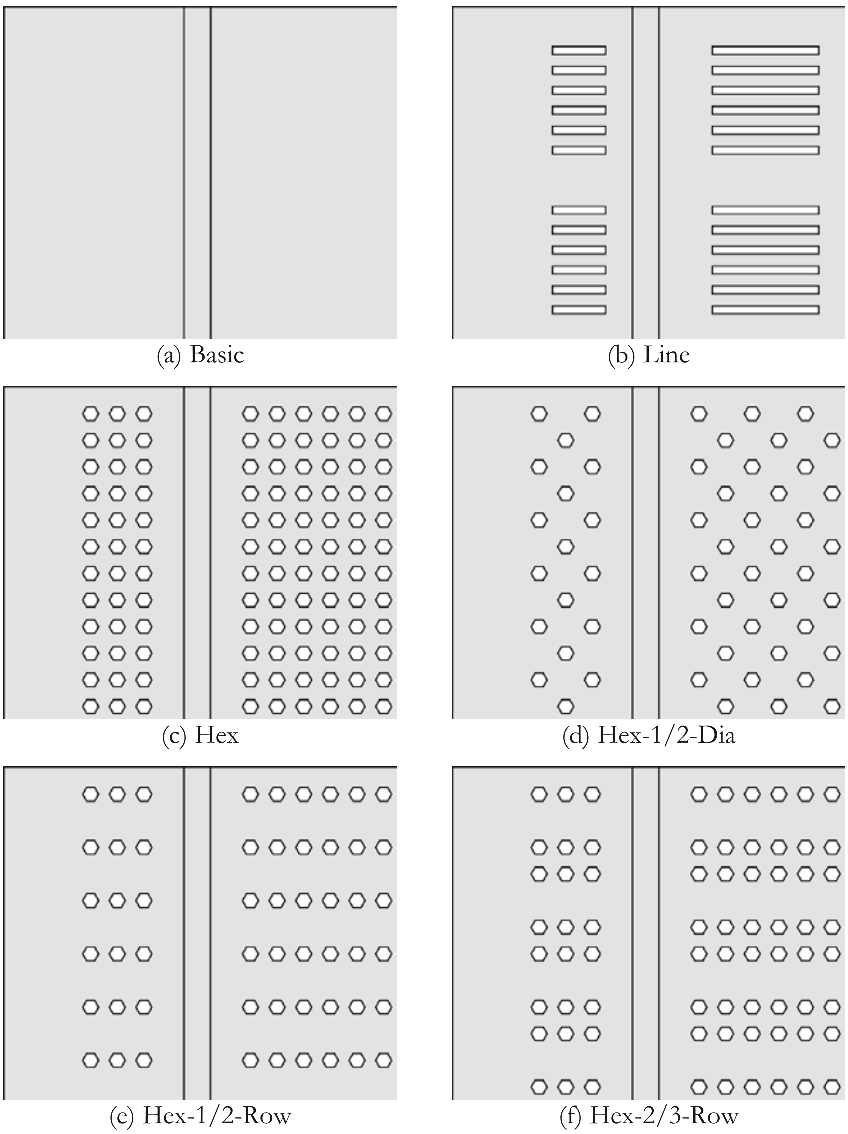

Figure 6. Illustration of the perforations in the combined gypsum and aluminium plates.

3 Results and analysis

The results show the impact of different design decisions on the thermal performance of radiant ceiling panels combined with diffuse ventilation.

3.1 Impact of acoustical perforations

The results for the acoustical perforation showed that the heat flux for the "Line" perforations are reduced with 7.4%, where the "Hex" showed a reduction of between 5.6-13.1% compared to the Basic plate without any perforations. A preliminary 3D-model of line-plate showed only a reduction of 3-4%. This means that the 2D heat transfer results presented in **Figure 7** should be conservatively reduced by the same magnitude.

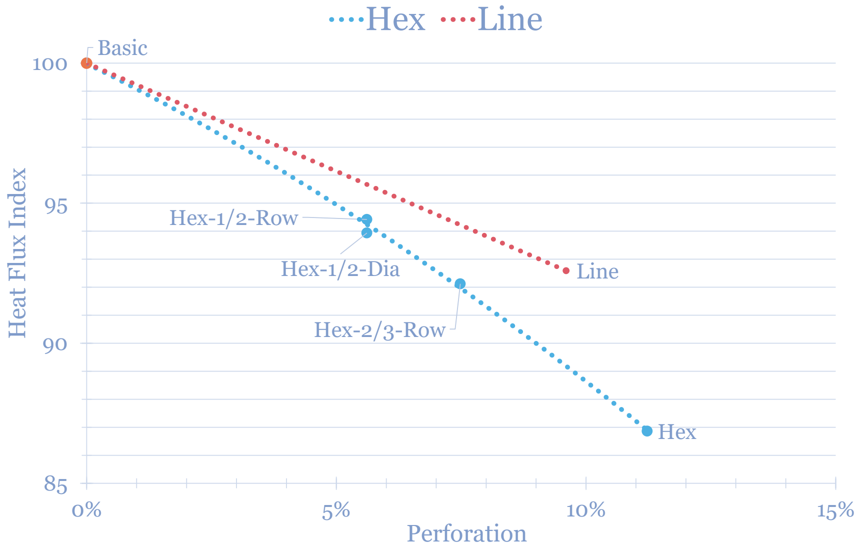

Figure 7. Heat flux of plate vs. perforation percentage.

3.2 Parametric study

Figure 8 show the temperature field of the reference model with different pipe spacing and a comparison with and without the aluminium plate. As it can be seen the effect of adding a heat distribution plate is quite significant on the temperature field.

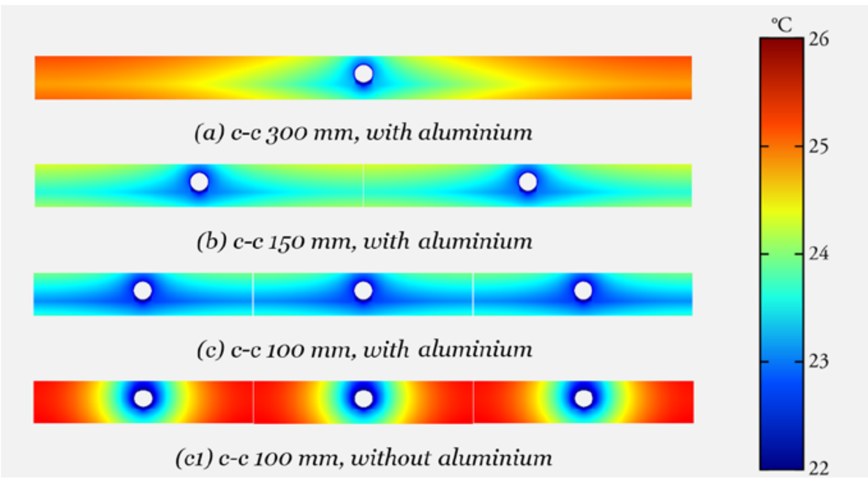

Figure 8. Temperature gradient of the reference model (a) with c-c 300 mm, (b) cc 150 mm, (c) cc 100 mm and (c1) cc 100 mm without an aluminium plate.

The surface temperatures for the reference model with aluminium can be found in **Figure 9**. Smaller distance between the pipes gives a more even temperature distribution on both upward and downward ceiling panel surfaces.

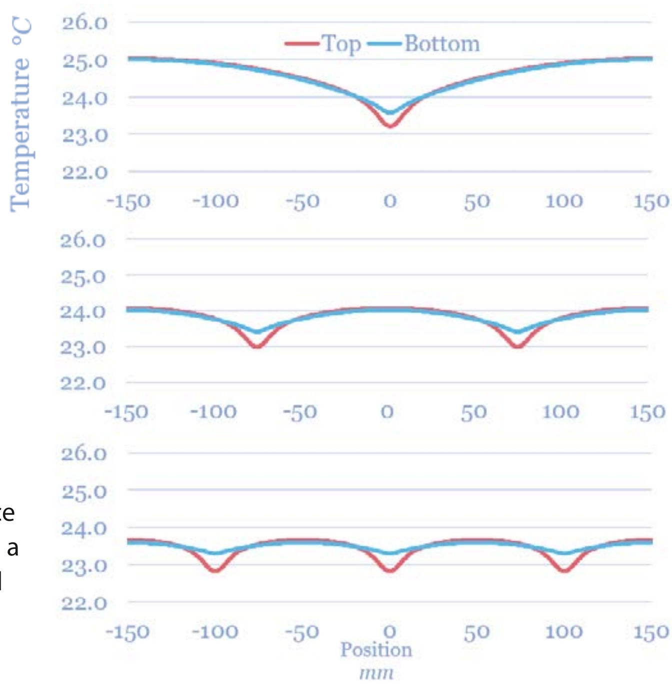

Figure 9. Surface temperatures for Reference model c-c 300, c-c 150 and c-c 100 mm with a water temperature of 22°C, and plenum and room air temperature of 26°C.

Figure 10 shows only a very small performance increase of using thicker aluminium. The impact is almost independent of pipe c-c distance.

The upward and downward heat transfer in relation to the upward surface heat transfer coefficient, i.e. the rate of diffuse ventilation, is shown in **Figure 11**. As expected, the effect on the top of the ceiling panel, hence the heat transfer from the ceiling panel to the plenum, is most significantly affected. The heat transfer to the room below is only changed by a small fraction.

When the reference gypsum board material is changed to a high-conducting gypsum-graphite blend, the heat transfer increases approx. 7%. Without the aluminium the effect of graphite board is larger (30–45%). However, looking at the heat transfer without aluminium but with graphite for the pipe spacing of 100 mm, and comparing with the pipe spacing of 300 mm with aluminium there is a small increase of 13% from the pipe spacing of 300 to 100 mm.

The heat transferred from the ceiling to the plenum re-enters the occupied zone, when the plenum air passes through the ceiling panel. The heat fluxes between

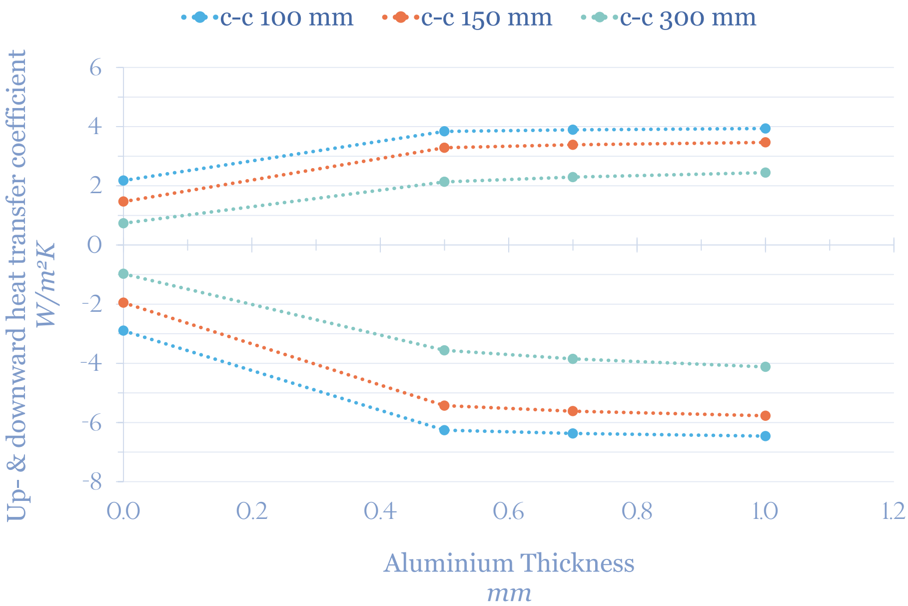

Figure 10. Up- and downward heat transfer coefficient with different heat distribution plate thicknesses.

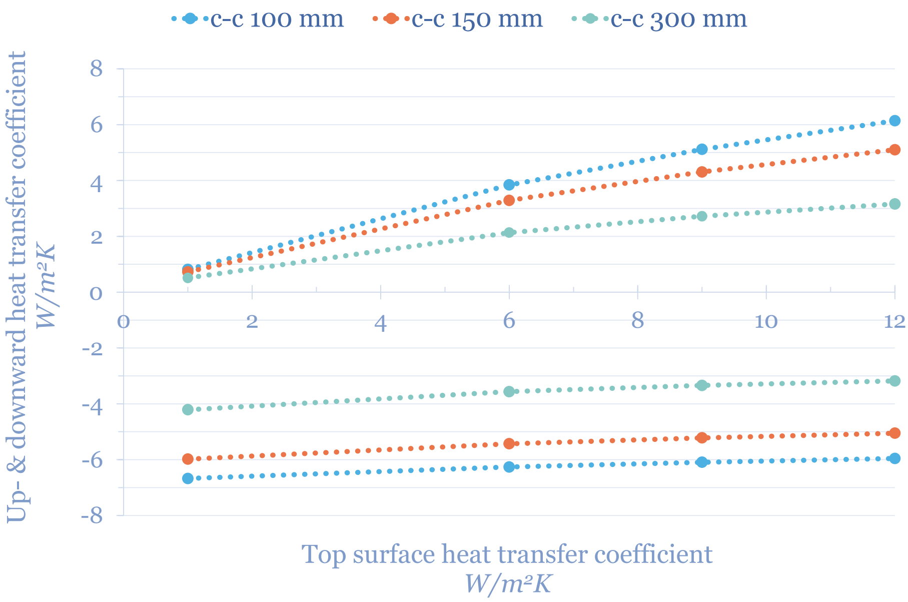

Figure 11. Up- and downward heat transfer coefficient with different top surface heat transfer coefficient.

HCVA panel, slab, occupied room and ventilation during operation of the systems are complex to deduct analytically and requires a full building simulation model to be investigated in detail.

The plenum walls and slab are essentially adiabatic except the façade wall, but to be conservative we assume that only 50% of the cooling initially 'lost' to the plenum is regained by the diffuse ventilation concept. This means the room is cooled by direct heat transfer from the ceiling panel and indirect heat transfer by the ventilation supply air due to pre-cooling in the plenum.

In **Figure 13** scenarios with different surface heat transfer coefficients ($h_{s,p}$) are compared to the reference model with index 100. The direct and indirect heat fluxes are lumped together assuming 50% of the indirect heat is regained. For the pipe spacing c-c 300 mm, the insulation on top of the ceiling ($h_{s,p}$ = 1 W/m²K) causes an increase on the total heat transfer from the ceiling of approx. 25%. In comparison the increase caused by adding diffuse ventilation (9 & 12 W/m²K) is 30%, but only with a small difference between high and low ventilation rates. For 100 mm c-c spacing, the total heat transfer is increased up to 45%.

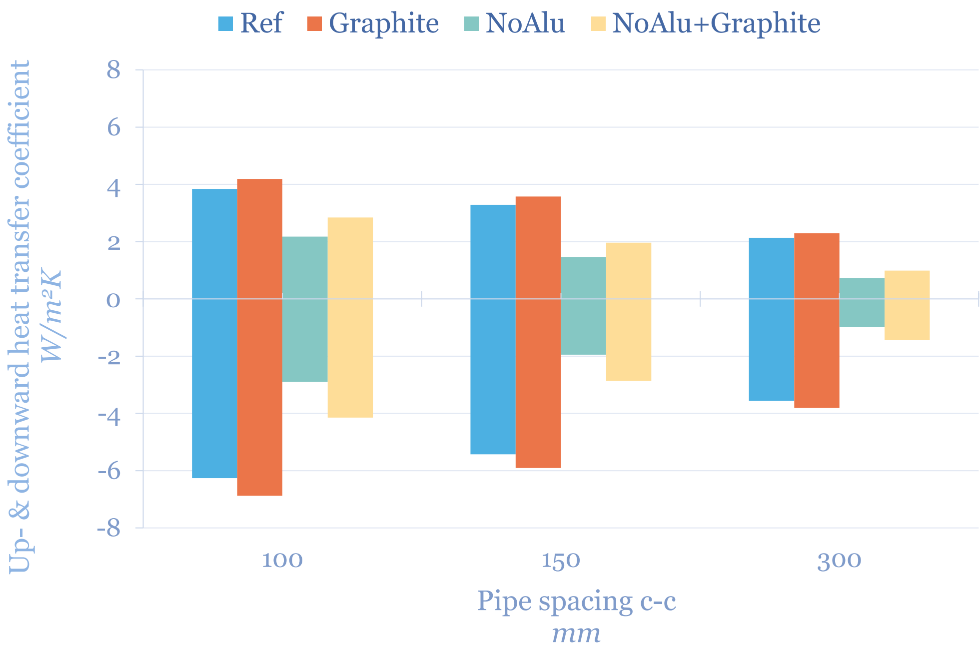

Figure 12. The effect of using a gypsum board material with higher thermal conductivity with and without aluminium plate.

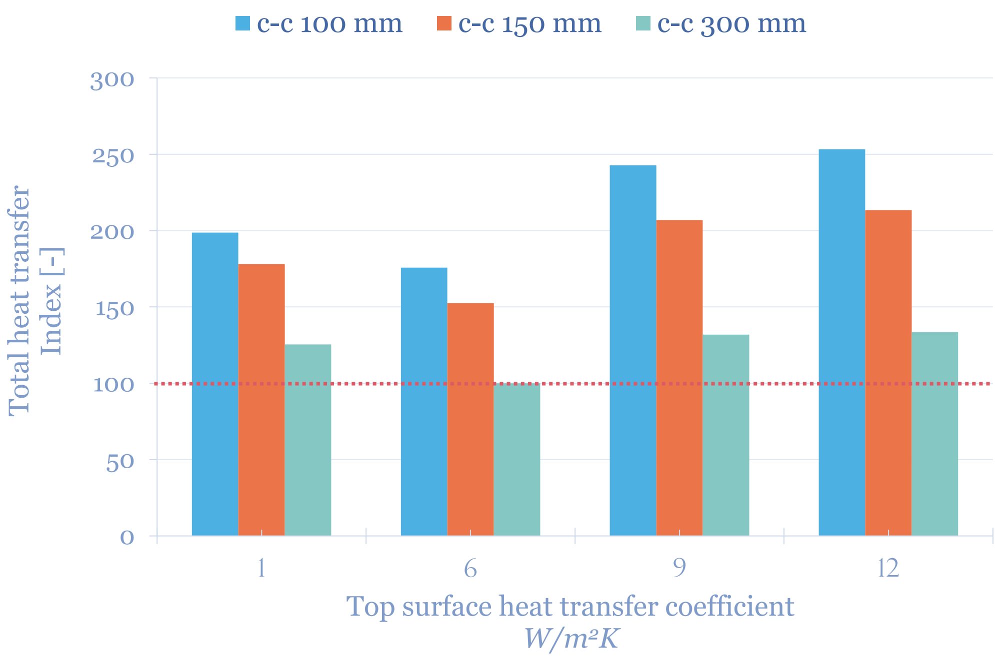

Figure 13. Total heat transfer index for the different top surface heat transfer coefficients. Index 100 is the reference model with c-c 300 mm with $h_{s,p}$ = 6 W/m²K.

4 Discussion

4.1 Impact of acoustical perforations

The perforations influence the total heat transfer. The investigations illustrated in this paper showed that the perforations are important to remember. However, the studies were made in 2D and preliminary studies showed the impact of the perforations is larger in 2D than in 3D. Consequently, further investigations should be carried out with 3D simulations to determine the exact decrease in the heat flux due to the perforations.

4.2 Parametric study

Adding the aluminium plate to the ceiling panel has a significant effect on the temperature field in that the cc300 mm with aluminium outperforms the cc100 mm without aluminium. The thickness of the aluminium plate does not have a significant impact. Adding graphite to the gypsum core has only a small impact when a heat conducting plate is implemented, however, for ceiling panels that rely only on small c-c spacing, the graphite increases the heat flux noticeably.

The downward heat transfer is almost not affected by the top surface heat transfer coefficient which is surprising as we expected insulation placed on top of the ceiling to be a performance increasing measure.

The assumption that energy initially 'lost' to the plenum is regained because of the diffuse ventilation concept is uncertain. It is influenced by the radiative and convective heat flux ratio in the plenum and the thermal storage capacity of the materials in the plenum and the daily temperature shift as well. The regain percentage will need further investigations in dynamic situations to disclose the true extra cooling capacity of the HCVA ceiling.

5 Conclusion

The overall objective was to quantify the effect of combining radiant ceiling panels with diffuse ventilation. We hypothesized correctly that the interaction between the ventilation air and the ceiling panel would cause the total heat transfer from water to room air to increase. In the process we studied the impact of a heat distribution plate, the spacing between pipes, gypsum material properties and the effect of the surface heat transfer coefficient in order to identify a number of solutions for an HCVA ceiling panel that combines heating, cooling, ventilation and acoustics with the best possible thermal performance.

Looking at the impact of adding the diffuse ventilation the heat transfer increases 30-45%. The difference between low and high diffuse ventilation rate was only 5%.

As a closing remark, we would like to acknowledge Saint-Gobain Nordic and Innovation Fund Denmark for financial support of this work. ■

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Decarbonization: exergy to the rescue

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Decoupling sustainable development from CO_2 emissions and global warming is the most urgent challenge of the World. While energy is required both in the forms of power and heat for sustainable growth and urbanization, CO_2 emissions follow a parallel trend with sustainable growth. i.e. CO_2 emissions continue to increase with sustainable development although 20+20+20 goals of EU are in place. These measures reduce the rate of increase in CO_2 emissions but cannot de-couple the relationship. This paper claims that exergy rationality may achieve the desired decoupling by following new recommended metrics for Decarbonization goals of the EU and gives a practical example of district heating with solar PVT panels.

1. Introduction

'We are paying for the quantity of energy but we are using only the quality (Exergy) of energy' – Prof.dr. Peter Novak[1]

The 20+20+20 goals of EU, namely 20% increase in energy savings, utilization of renewable energy sources, and efficiency, respectively each, may all reduce the CO_2 emissions rate but are not sufficient to reverse (decouple) the ongoing parallel trend with sustainable growth. In Eq. 1 and **Figure 1**, these three goals are supplemented hereby with a fourth goal, namely exergy rationality, expressed by the term ψ_R. This is the rational exergy management model (REMM) efficiency, which watches the balance between the quality of energy among supply and demand points in the built environment. In **Figure 1** HSDI is the Human (Sustainable) Development Index defined by UNDP and will replace HDI (Human Development Index) only if CO_2 emissions rate falls below the 1990 level. Eq. 1 shows that CO_2 emissions may be substantially reduced by increasing the exergy rationality, because there is a large window of opportunity between the current global ψ_R average of 0.20 and the practical bound that may exceed 0.70, without facing the dilemma of the diminishing returns, like the other goals of EU strategies face today.

It is clear that, if and only if, CO_2 emissions are reduced by increasing ψ_R by reorganizing human activities by exergy rationality to such a level that natural sinking mechanisms assisted by artificial capture of CO_2 emissions can take over and let CO_2 emissions go below 1990 levels. Eq. 3, and **Figure 2** show that exergy destructions must be minimum.

$$\sum CO_2 = \frac{RENEWABLES}{EFFICIENCY}(2-\psi R)\ SAVINGS \qquad (1)$$

$$\psi_R = \frac{\varepsilon_{dem}}{\varepsilon_{\sup}} \quad \text{\{Exergy destroyed upstream\}} \qquad (2)$$

$$\psi_R = 1 - \frac{\sum \varepsilon_{des}}{\varepsilon_{\sup}} \quad \text{\{Exergy destroyed downstream\}} \qquad (3)$$

1 Honorary Member of IIR, 2003, Fellow and Life Member of ASHRAE 1999; Honorary Member of REHVA, SITHOK and SLOSE.

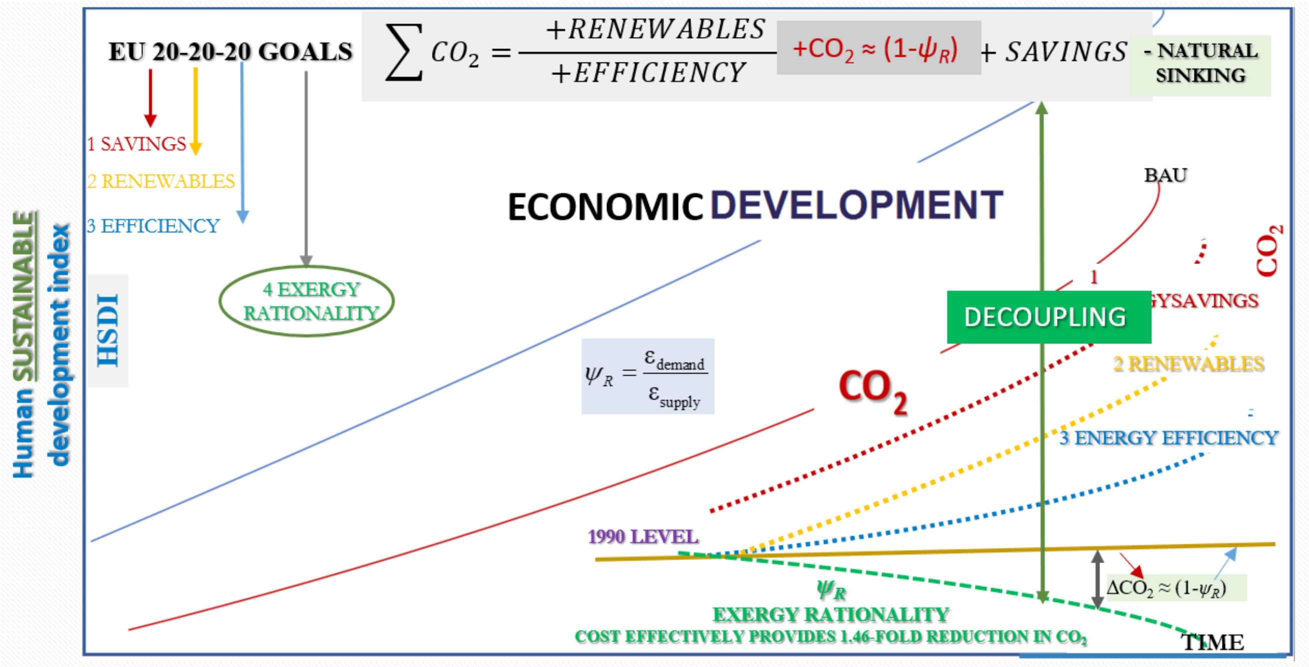

Figure 1. Phases of De-Coupling Between Emissions and Sustainable Development: Role of Exergy.

Here ε is the unit exergy (W/W) defined by the ideal Carnot cycle between two temperatures T_1 and T_2 of a process.

$$\varepsilon = \left(1 - \frac{T_1}{T_2}\right) \tag{4}$$

Current EU strategies about electrification of heating and cooling with heat pumps do not make much sense for the Second-Law of Thermodynamics: a natural gas-fired thermal power plant burns natural gas at T_f= 2200 K and electricity is used by a heat pump with a *COP* of 3 for radiant floor heating at supply and return temperatures of 330 K and 320 K, respectively. Then, exergy-based *COP*, namely *COPEX* is less than one due to large exergy destructions (See **Figure 2**) and ψ_R, which is responsible for CO_2 emissions is quite small. For an exergy-rational system (*COPEX*→1) *COP* must approach to 28.7, which is unpractical today. 283 K is the reference temperature, T_{ref}.

$$\psi_R = \frac{1-320/330)}{(1-283/2200))} = 0.035 \quad \text{\{See Equation 2\}}$$

$$COPEX = COP \cdot \psi_R = 3 \times 0.035 = 0.105 \tag{5}$$

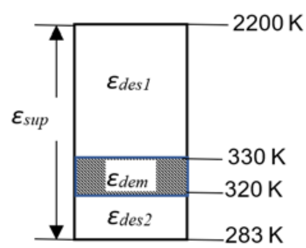

Figure 2. Exergy Flow Diagram (Eq. 2).

2. Justification of the Study

Today's limited ability to cope with the real issues that affect sustainability, global warming, and energy security, originates from the fact that all energy projections, model studies, carbon emission predictions, and mitigation calculations, international protocols, and energy system designs are based only on the quantity of energy efficiency, leaving the root cause beyond touch. In fact, thermodynamic irreversibility that impacts harmful emissions with the end result of global warming lies within the new scope of rational exergy management, which deals with the **quality** of energy resources and the quality of energy required for different applications in the built environment. With current systems, which largely count on fossil fuels, there is an unbalance among them, that compounds energy spending and harmful emissions because the opportunities of fully utilizing the quality of energy resources are missed. A simple exergy input and output type of exergy balance, similar to the energy balance cannot provide the scale of the unbalances taking place today at large either. **Figure 2** is the fundamental tool shown above to find the missing piece of the puzzle and establish the missing link. A key definition and a new methodology are necessary to bring all the energy supply, demand, and environmental issues and parameters on a common platform with a unified metric of rational allocation of energy resources in both quality and quantity. This is especially essential with the diversification, hybridization, and systems approach of the EU along with the increasing share of renewable energy resources, smart cities, and low-energy and low-exergy buildings (Sustainable and green buildings). All EU Directives, being issued so far are based however on the First-Law, which recognizes only the quantity of energy. In fact, every energy resource has a different quality, named exergy, which is the amount of useful work that can add value to the society and to the built environment at large, if utilized properly from a given amount of energy of a given type and quality. According to the Second-Law, it is important to use the right quality of energy at the right balance of quality demand at a given application, at the right time, and at the right order in addition to the right quantity (energy). Therefore, it is crucial to establish also a quality balance among different sources of energy having different exergy and different energy demand points at different exergy. This requires a new exergy allocation methodology and re-wiring of energy sources among all energy demand points. Even the forms and quantity of energy sources are balanced, with the demand points, remaining exergy imbalances cause exergy destructions, which are responsible for additional energy demand and additional – but avoidable – CO_2 emissions, which are all invisible to the First-Law. Rational Energy Management Model [1] is the potentially key rescue mission to global warming and decoupling issues. Sustainable buildings of today are thermodynamically interconnected to the built environment, because buildings generate, share, and consume energy with all elements of the built environment, which also need to be sustainable. Such a level of interconnection along with the hybridized utilization of renewable energy sources, including reject heat of different types, temperatures, and exergy also makes it necessary to acknowledge and identify the existence of different sources and demands of exergy in different forms, temperatures, and locations. This further necessitates a holistic approach.

3. EU Literature

The only European initiative about the inclusion of exergy in EU energy analyses is published by Science Europe [2]. In appreciation and thanks to the motivation and insight into the subject matter by the Authors of this important publication, namely Dr. Paul Brockway, University of Leeds, Professor Jo Dewulf, University of Gent, Professor Signe Kjelstrup, Norwegian University of Science and Technology, Professor Susanne Siebentritt, University of Luxembourg, Professor Antonio Valero, CIRCE, Research Centre for Energy Resources and Consumption, University of Zaragoza, Dr. Caroline Whelan, Science Europe, their following statement is hereby repealed. In quote:

'Educators, researchers, policymakers, stakeholders, and citizens are urged to consider energy and natural resources on the basis of exergy, and in doing so understand that:

- *exergy measures energy and resource quality;*
- *exergy-destruction foot-printing improves industrial efficiency;*
- *exergy offers a common international energy-efficiency metric;*
- *optimal use of our limited mineral resources can be achieved by the application of exergy rarity;*
- *and exergy should be integrated into policy, law and everyday practice.'*

4. Transformation of Non-Thermal Renewables

Mechanical energy, E of all types like the kinetic energy of flow, the potential energy of stored water of mass, m and specific heat, C_p may be mapped into the Carnot-cycle temperature field by a virtual source temperature, T_f by using the equivalency of energy and heat by Kilkis [2]. This relationship reduces to the following expressions for solar and wind energies, respectively.

$$\frac{I_n}{1366} = \frac{\left(1-\dfrac{T_{ref}}{T_f}\right)}{\left(1-\dfrac{T_{ref}}{5778K}\right)} \tag{6}$$

$$T_f = \frac{T_{ref}}{\left(1-\eta_w\right)} \tag{7}$$

η_w is the efficiency of the wind turbine. 1366 W/m² is the solar constant.

5. CO_2 Emissions and Exergy Rationality

The compound CO_2 emissions, including the effect of exergy destruction, is given in Equation 8.

$$\sum CO_2 = \left[\frac{c_I}{\eta_I} + \frac{c_m}{\eta_m \eta_T}(1-\psi_R)\right] Q_H + \frac{c_m}{\eta_m \eta_T} E \tag{8}$$

This Equation, which is derived from the Rational Exergy Management Model (REMM), establishes the environment metric. If renewable energy sources are the primary energy source and power is also generated, then the first and the last terms drop.

The following expression, namely *EDR* is the *Ratio of Emissions Difference*, which must be close to one.

$$EDR = 1 - \left[\frac{CO_2}{CO_{2\ \text{base}}}\right] \tag{9}$$

The term $CO_{2\ \text{base}}$, which is 0.63 kg CO_2/kW-h is the standardized emission rate calculated with practical defaults for 0.5 kW-h thermal and 0.5 kW-h electrical loads per hour. *c* values are based on natural gas (0.2 kg CO_2/kW-h, 0.85 is the typical boiler efficiency, and 0.35 is power generation and transmission efficiency. The current global average of ψ_R is taken to be 0.2.

6. Recommendations

Above review reveals that the Second-Law provides further insight and ability to further decarbonize EU and the globe in a more realistic and effective way, beyond the point where the First-Law stops. The key parameter, namely the ψ_R is a derivation from the Carnot Cycle in terms of supply and demand exergies. Thus, a simple transformation of all EU directives is possible by applying the factor ψ_R, which is shown in **Table 1**. For cold processes where the temperatures are below T_{ref}, the term (T_{ref}/T_s) in all equations are inverted.

Table 1. Sample Transfer Functions for EU Directives.

EU Terms (Sample)	First-Law Definition	Second-Law	Comments
Performance coefficient	*COP*	COP_{EX}	Multiply *COP* by ψ_R.
Primary Energy Ratio	*PER*	*PEXR*	(Inverse of *PEF*) Multiply *PER* by ψ_R.
Primary Energy Factor	*PEF*	*PEFX*	Divide *PEF* by ψ_R. Apply to electrical and thermal power separately.
Primary Energy Savings	*PES*	PES_{EX}	Cogeneration applications. Eq. 14.
Tonne oil equivalent	*Mtoe*	*MtoEX*	Multiply Mtoe by ψ_{RF}.

Exergy-Based PER (Inverse of PEF)

$$PER = \frac{Q_S}{Q_f / (\eta_{ITH} \cdot COP)} \tag{10}$$

$$PEXR = \frac{E_{Xs}}{E_{Xf}/\eta_{ITH}} = \frac{\varepsilon_s \cdot Q_s}{\varepsilon_f \cdot \frac{Q_s}{(\eta_{ITH} \cdot COP)}} = \frac{\left(1-\frac{T_{ref}}{T_s}\right)}{\left(1-\frac{T_{ref}}{T_f}\right)} \cdot (\eta_{ITH} \cdot COP) = \psi_R \cdot PER$$

{From fuel input at the plant to the point of use} (11)

$$PEXR = \eta_{ITH} \times COP_{EX} \tag{12}$$

Exergy-Based PEF

$$PEFX = \left(\frac{1}{\psi_R}\right) \cdot PEF \tag{13}$$

Because the exergy of electric power and thermal power at different temperatures and enthalpy have a great difference, *PEF* and *PEFX* need to be broken down to thermal and electric power separately.

Exergy-Based PES (For co-generation)

$$PES_{EX} = \left(1 - \frac{1}{\left[\frac{CHPE\eta}{\mathrm{Re}fE\eta} + \frac{CHPH\eta}{REFH\eta}\right] \times \left(\frac{2-\psi_{R\,ref}}{2-\psi_R}\right)}\right) \times 100 \tag{14}$$

Exergy-Based Mtoe

$$MtoEX = \frac{\left(1-\frac{T_{ref}}{T_s}\right)}{0.881} \times Mtoe = \psi_{RF} \times Mtoe \tag{15}$$

Here, ψ_R is indexed to the unit exergy of crude oil, ε_F, namely 0.881 W/W.

From the exergy point of view, it has been shown above in terms of *PEXR* that once the electrical power is generated- even from solar or wind- it must stay as electrical power instead of converting it to thermal power unless the average *COP* value of heat pumps in heating reach beyond a value of 8. This also shows that one needs a common base by converting exergy to cost or vice versa. In this respect, the cost of exergy destruction per unit supply exergy may be embedded into cost equations, like life cycle cost analysis optimizations. *c* is the unit cost.

$$\Delta C_{EX} = c_{EX} \frac{\sum \varepsilon_{des}}{\varepsilon_{\sup}} \quad (16)$$

7. Case Study

A solar PVT plant serves a 4DE district energy system. Power is partially used to drive the circulation pumps in the district. The rest of the generated power is distributed in the grid for electrical demand of different types and purposes, including mass transit. Hot water is distributed by a system of pipelines in the district. This heat may be converted to cold by individual absorption and or adsorption units on site of customers, on demand. **Figure 3** shows the basics of the system. The common mistake in the design and operation of such systems is the ignorance of the unit exergy difference between electrical and thermal powers. Among all ancillaries, which demand power circulation pumps need to be carefully optimized such that thermal exergy provided to the district must exceed electric power exergy demand of the pumps, ignoring other parasitic losses and ancillary demand.

$$E_{XH} > E_{XP}(D, L) \quad (17)$$

Here E_{XP} is a function of the pipe diameter, D and the one-way distance of the loop between the PVT plant and the district, L. For the limiting case of Equation 15 and the given installed capacity, C of the PVT plant, providing heat to the district between 330 K and 320 K, feeding radiant panel heating and at the same time providing in a parallel piping heat at 340°C for DHW and to avoid Legionella risk in open systems, like showers and faucets. Thus, the overall exergy supply to the district takes place between 340°C and 320°C:

$$E_{XH} = C\left(1 - \frac{320}{340}\right) = 0.059C$$

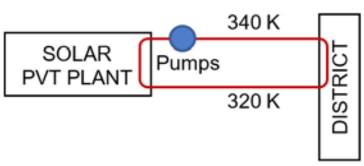

Figure 3. District Energy System with Solar PVT Plant.

If for example, the power demand of the installed pump stations, P_s is 15% of the thermal capacity, C, COP of the district energy system between the plant supply and district demand points looks quite favourable:

$$COP = \frac{C}{P_s} = \frac{C}{0.15C} = 6.7$$

But *COPEX* tells a different story:

$$COPEX = \frac{0.059C[\mathrm{W/W}]}{0.15\mathrm{C}[1\mathrm{W/W}]} = 0.39$$

1 W/W is the unit exergy of electricity. From Equation 5, ψ_R is 0.058 and the corresponding CO_2 emissions responsibility (Although Solar Energy is the Primary Source) may be calculated from Equation 9. In order to improve the exergy performance of the system pipe diameter may be increased, which affects the Reynolds number but at the same time the flow speed in terms of the flow rate and the inner pipe cross-sectional area. A larger but optimal pipe diameter may be determined but Reynolds Number, *Re* must be above a certain limit for turbulent flow and the increase in the embodied energy, exergy, and cost corresponding to the pipe diameter increase must be balanced by the cost of electricity generation and operating exergy. The maximum L, namely L_{max} is related to exergy.

$$L_{\max} < \frac{E_{XH}}{\Delta P_S(1)} \quad (18)$$

Therefore, the distance from the plant to the district is a function of the supply and pump demand exergy. Piping material is also important.

Electric power is in DC in order to avoid inverters and re-conversion to DC in some household equipment like TV screens, LED lighting, and computers.

8. Conclusions

The study presented in this paper shows the need to approach the Second-Law of Thermodynamics if EU wishes sincerely to pursue decarbonization further with all fairness to all stakeholders. Such a move will also become a role model for all other countries of the World. In quantified terms, the task is not of a paramount magnitude. Instead, **Table 1** shows that a single key term, namely ψ_R shall transform all directives and rules in a simple fashion with a new mindset and perspective towards the exploitation, generation, transformation, and utilization of our limited energy resources for a truly sustainable future that we all envision.

We should use;

- The right quality of energy,
- At the right application,
- At the right order of utilization,
- At the right time and,
- At the right location.

In conclusion, what EU needs is a strong willingness, motivation, mobilization of the stake-holders and mindset to accomplish such a monumental task with minimal effort with minimal transformation, simply by using a few key parameters. Such a move will especially be useful and effective in the decoupling process for new 4DE systems.

Furthermore, solar energy plants need to be optimally hybridized by other renewables, including district waste for biogas, with support from fossil fuels if necessary [3,4]. In order to improve *COP* and *COPEX*, Low-Exergy Buildings must be designed and installed along with high-efficiency pumps and electric motors need to be utilized [6]. ■

9. Nomenclature

A_d	Pipe inside the cross-sectional area, m²
c	Unit emissions factor, $kgCO_2$/kW-h
c_{EX}	Unit cost of exergy destruction Euro/kW-h
C	Thermal plant capacity, kW or MW
$CHPE\eta$	Partial power generation efficiency
$CHPH\eta$	Partial heat generation efficiency
CO_2	Carbon dioxide emission, kg CO_2
COP	Coefficient of Performance
$COPEX$	Exergy-Based Coefficient of Performance
E	Electrical energy (load), kW-h
EDR	Ratio of carbon CO_2 emissions difference to the base emission, dimensionless
E_x	Exergy, kW or kW-h
I_n	Net solar insolation normal to PVT, /m²
L_{max}	Maximum district piping distance (one way), km or m
$Mtoe$	Megaton of oil equivalent
$MtoEX$	Exergy embodied Megaton of oil equivalent
PEF	Primary energy factor
$PEFX$	Exergy embodied primary energy factor
PER	Primary energy ratio
PES	Primary energy savings ratio
PES_{EX}	Exergy embodied primary energy savings ratio
$PEXR$	Exergy-based primary energy ratio
Q, Q_H	Thermal energy (load), kW-h
$RefE\eta$	Reference power generation efficiency
$RefH\eta$	Reference heat generation efficiency
T	Temperature, K
V	Volumetric Flow, m²/h
L	One-way Circuit Length, km
P	Pressure, Pa
P_s	Power demand for pump stations, kW
ΔP_s	Power demand for pump stations per kilometer of the pipe circuit in the district, kW
D	District Pipe Inner Diameter, m
Re	Reynolds Number

Greek Symbols

η_{EX}	Second-law efficiency, dimensionless
η_T	Power transmission and distribution efficiency
ψ_R	Rational exergy management efficiency
ε	Unit exergy, kW/kW
η_I	First-Law Efficiency
η_{II}	Second-Law Efficiency
μ	Dynamic Viscosity, kg/m-s
ΔC_{EX}	Cost of exergy destuctio, Euro

Acronyms

CHP	Combined Heat and Power
DHW	Domestic hot water
DC	Direct current
4DE	Fourth-Generation district energy system
EU	European Union
HDI	Human Development Index
HSDI	Human Sustainable Development Index
Mtoe	Megaton of oil equivalent (According to the First-Law)
MtoEX	Megaton of oil equivalent exergy (According to the Second- Law)
PVT	Photo-voltaic-thermal
REMM	Rational Exergy Management Model
UNDP	United Nations Development Program

Subscripts

base	Base
dem	Demand
des	Destroyed
E	Electric
f	Resource temperature, or Adiabatic Flame Temperature (Real or virtual), K
F	Crude oil
H	Thermal (Heat)
in, out	Inlet and outlet connections of a hydronic circuit
l, m	Local power plant, distant power plant, respectively
min, max	Minimum, maximum
ref	Reference
sup, ret	Supply, Return
s	solar
o, ref	Reference
p	Pump
T	Power transmission
w	Wind
X, EX	Exergy, exergetic

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Simulation Optimization on Heat Transfer Characteristics of Carbon Dioxide in Microchannel Evaporator

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Keywords: CO_2, Heat transfer characteristics, Microchannel evaporator, Simulation model

Abstract

Simulating model based on a specific CO_2 microchannel evaporator was established through control volume method with MATLAB, in which both wet and dry conditions for air side, and two-phase and overheat zones for CO_2 side have been considered during the evaporative process. Simulation results showed little discrepancy with pervious experimental data which validates the model. And then the heat transfer characteristics in microchannel evaporator were simulated under different inlet air parameters. It was shown that air velocity has the greatest impact on heat transfer effect, followed by air temperature, and air humidity at last. Meanwhile, the dry-out point also has an important impact on heat transfer performance: before the dry out happens, the heat transfer coefficient of the CO_2 increased with higher air temperature, relative humidity and velocity, while after the dry out occurs, there has been a drastic decline of convective heat transfer coefficient. Therefore, the dry-out point should be postponed for better performance. Then, structural optimization has been made by utilizing two-stage series evaporators. Corresponding simulation results showed that 37.5% area of the original experimental device can still achieve 90.5% heat transfer rate of the former one. So, this method can greatly improve the heat transfer effect of the CO_2 microchannel evaporator.

This article is the winner of HVAC World Student Competition award, see news on page 90.

Introduction

The main devices of heat transfer in the refrigerating cycle of CO_2 have been going through the development from the finned tube style to the microchannel style. Compared to the traditional heat exchanger, the micro-channel heat exchanger is usually smaller and higher heat transfer coefficient, but it's pressure resistance and drop is higher, which may easily cause congestion and imbalanced distribution of fluid. CO_2 can cover the shortage of microchannel heat exchanger due to its low ratio between liquid and gas density [1]. However, when the hydraulic diameter is smaller than 3mm, the two-phase flow and heat transfer regulation differs from the normal size. More noticeable microscale effect can be observed in narrow passageway [2].

Many research institutions have studied on this issue that mainly focus on the boiling heat transfer coefficient of the two-phase field, critical heat flux, dry-out point, two-phase flow pattern and pressure drop model [3]. Cheng et al. have discovered that the critical dryness of carbon dioxide was generally between 0.5 and 0.7, which was much lower than that of R22 with a critical dryness usually between 0.8 and 0.9 [4]. Then, they have considered the characteristics of intermittent flow, annular flow, dry-out inception and mist flow to modify the boiling heat transfer correlation under the basis research of Wojtan [5]. Zhang has established a two-dimensional distributed parameter model for the CO_2 microchannel evaporator and proposed a modified heat transfer correlation after comparing to the experimental data [6].

Several appropriate heat transfer correlations are selected according to the heat transfer characteristics of CO_2 in microchannel evaporator, and comprehensively considered the different heat transfer characteristics of wet and dry conditions on air side along with two-phase region and overheated region of CO_2. Parameter distribution simulation model of CO_2 microchannel evaporator has been established and verified through the experimental results. Finally, structural optimization has been proposed and verified through further simulation under different channel number, air temperature, humidity and velocity have been analyzed for studying their impact on heat transfer performance.

I. Experiment Research

A. Microchannel evaporator

Experiment research on a parallel flow micro-channel evaporator which is composed of 36 parallel flat tubes, each of which has 18 microchannels with equivalent diameter of 1.096 mm. The two-phase CO_2 coming from the collecting pipes flows into the microchannel and exchanges heat with the air in the louver fin between the microchannels. **Figure 1** is the structure of the microchannel evaporator and it's detailed 3D diagram. The calculated main structural parameters are shown in **Table 1**.

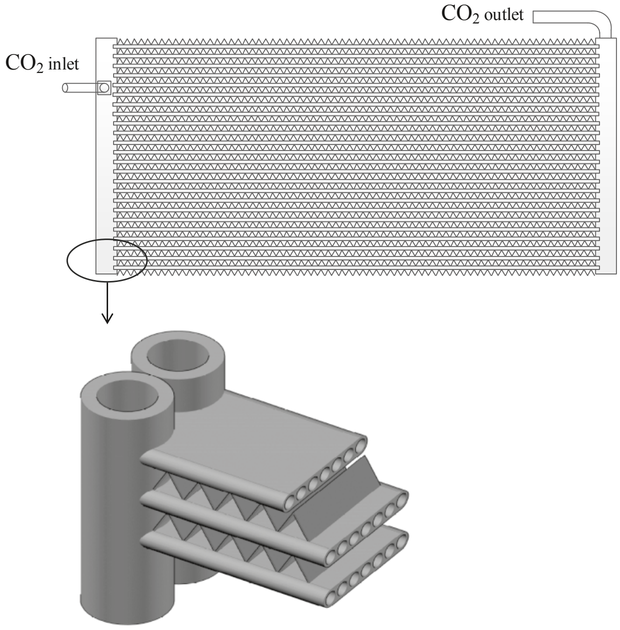

Figure 1. Diagram of the microchannel evaporator.

Table 1. Main structural parameters of microchannel evaporator.

Upwind surface Width/Height (mm)	Air direction depth (mm)	Volume (cm^3)	Heat exchange area (m^2)		Equivalent diameter (mm)
			Air side	Refrigerant side	
810/50	25	7087.5	9.46	2.28	1.096

B. Experimental system

The experimental table of the CO_2 microchannel evaporator was set up (see **Figure 2**). The conditions of the evaporator side are provided by the Enthalpy Different Laboratory. The platinum resistances and pressure transmitters were installed in the evaporator inlet and outlet in order to measure the temperature and pressure of CO_2. Thermocouples were fixed on the surface of the evaporator to measure it's tube temperature. The temperature, humidity and speed of air side were measured by thermometer, hydrometer and anemometer. Finally via the electronic expansion valve, the dryness and mass flow rate of CO_2 at the inlet of the evaporator was adjusted.

C. Experimental results

The 18^{th} flat tube was analyzed and divided into 9 sections, which is 90 mm with measuring points set in the center of each section. The incipient air temperature is set to 23°C, and relative humidity is 25%, so the dew point temperature is 2.14°C.The experiment measured CO_2 mass flow rate, inlet dryness, pressure, evaporation temperature, wall temperature, air temperature, humidity and speed which are shown in **Table 2** and **Table 3**. The convective heat transfer coefficient and heat transfer amount of each section of this flat tube would be calculated according to the experimental data, which are shown in **Table 2** and **Table 3**. **Table 4** is the convective heat transfer coefficient and heat transfer amount along the length distribution.

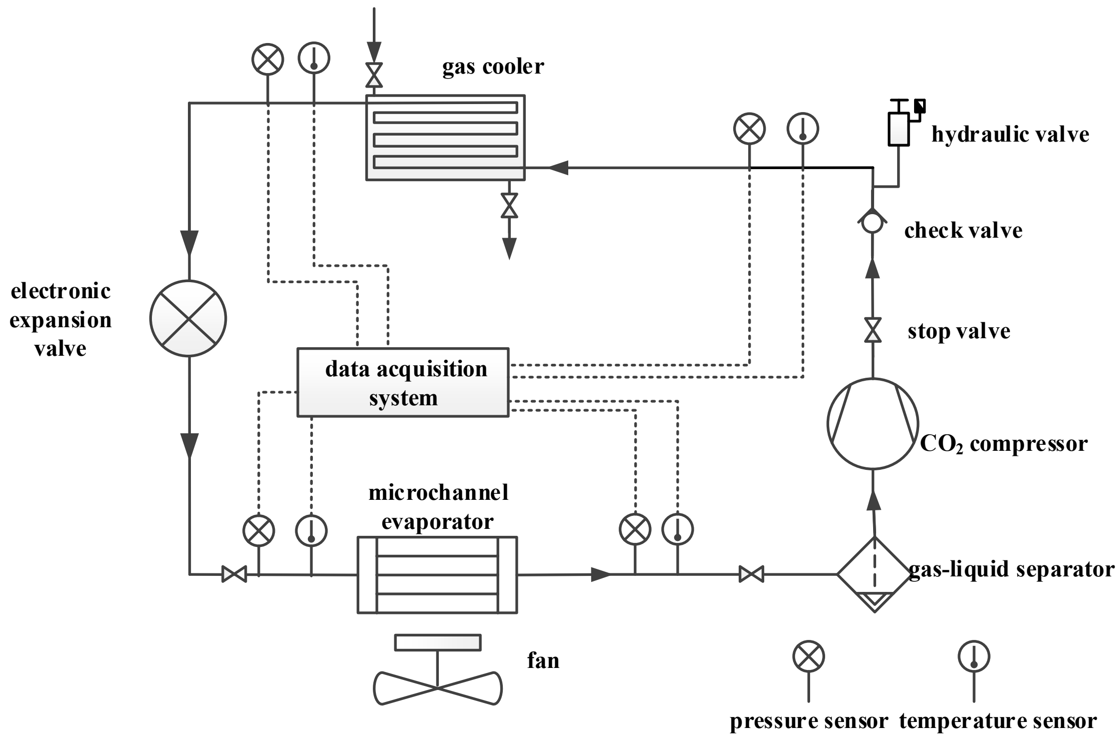

Figure 2. The experiment system diagram.

Table 2. Experimental measurement values of CO_2 side.

Category	Mass flow (g/s)	Inlet dryness	Inlet pressure (MPa)	Outlet pressure (MPa)	Outlet Temperature (°C)
Measured values	15.67	0.28	3.22	3.18	11.58

Table 3. Distribution of Parameters.

Measuring points	1	2	3	4	5	6	7	8
Wind speed (m/s)	1.4	1.9	1.6	1.4	1.8	1.8	1.9	1.8
Outlet temperature (°C)	22.4	22.1	21.7	21.1	19.0	8.2	6.5	5.9
Outlet humidity (%)	26.5	26.8	27.6	28.9	32.7	66.1	60.0	61.1
Wall temperature (°C)	22.8	22.1	21.5	20.5	17.1	6.0	–1.7	–1.9

Table 4. The convective heat transfer coefficient and heat transfer amount along the length distribution.

Length (mm)	45	135	225	315	405	495	585	675	765
Convective heat Transfer coefficient (W/m² K)	5033.6	4742.3	820.9	156.7	149.2	148.2	147.2	146.3	145.2
Heat exchange amount (W)	30.64	30.90	22.00	5.94	2.14	1.23	1.13	1.02	1.01

II. Simulation Model

A. Heat transfer correlation of CO_2 side

1) Overheated region

According to the different evaporator outlet states of CO_2, the refrigerant flow can be divided into two-phase region and overheated region. As for the overheated region, different heat transfer correlations were selected according to the Reynolds number: When $Re \geq 2300$, the convective heat transfer coefficient was calculated by Gnielinski formula [7]; When $Re < 2300$, the convective heat transfer coefficient was calculated by Sieder-Tate formula [8].

2) Two-phase region

The currently available CO_2 boiling heat transfer correlations are mainly Shah, Gungor and Winterton, Hwang, Yoon, and Cheng correlations. In Cheng correlation, the whole two-phase region is divided into 3 phases as the intermittent flow, annular flow and mist flow according to the boundary point of intermittent flow and annular flow and the dry-out point. Compared with the experimental data in the reference [9], the Cheng correlation was considered to be the most accurate in this experimental condition. So the Cheng correlation was selected in our simulation.

B. Heat transfer correlation of air side

When the wall temperature is below the air dew point temperature, dew will occur on the surface of the flat tube. So the dry and the wet working conditions should be both considered to analyze the heat transfer on the air side. Many research focus on dry condition, while regardless of wet condition. In the wet condition, the surface thermal resistance increases and the heat transfer coefficient will be much smaller. The correlations developed by Kim and Bullard can predict accurately about the heat and mass transfer performance of the shutters both in dry and wet conditions [10]. So their correlation was used in our simulation model.

C. Controlling equations

In order to make the process of calculation easier, the mathematical model of CO_2 microchannel evaporator was assumed as follows:

1) CO_2 is equally divided into flow each microchannel;
2) No thermal conduction or heat resistance exists between microchannels;
3) CO_2 side and air side are both steady flow;
4) The air on the condensation water surface is saturated and the thermal resistance of the condensed water is negligible;
5) The effect of lubricating oil and noncondensing gas is not considered.

Making the flat tube and the 1/2 louver fin on the upside and underside of it as the research object, the control unit is shown in **Figure 3**.

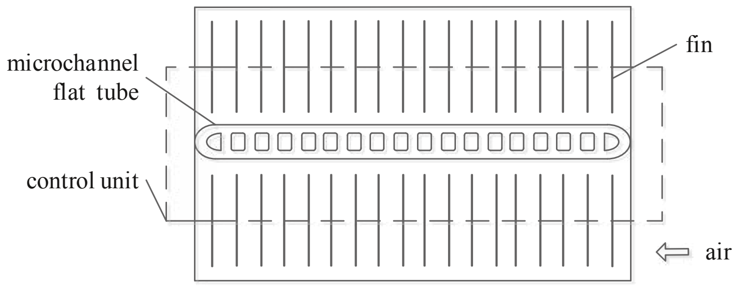

Figure 3. Sectional view of control unit.

As shown in **Figure 4**, every control volume can be regarded as a small cross flow heat exchanger, which was analyzed by energy conservation:

Air side heat exchange: $$Q_{a,j} = M_{a,d}\left(h_{ai,j} - h_{ao,j}\right) \quad (1)$$

CO_2 side heat exchange (two-phase): $$Q_{r,j} = M_r\left(x_{o,j} - x_{i,j}\right)i_{tp} \quad (2)$$

CO_2 side heat exchange (overheated): $$Q_{r,j} = M_r\left(h_{o,j} - h_{i,j}\right) \quad (3)$$

Where Q represents heat transfer rate (W), M the mass flow rate, (kg/s), h the enthalpy(kJ/kg), x the dryness, and I the latent heat of vaporization(kJ/kg).

Where subscript abbreviation a represent air, r refrigerant, i inlet, o outlet, tp two-phase, j the j control volume.

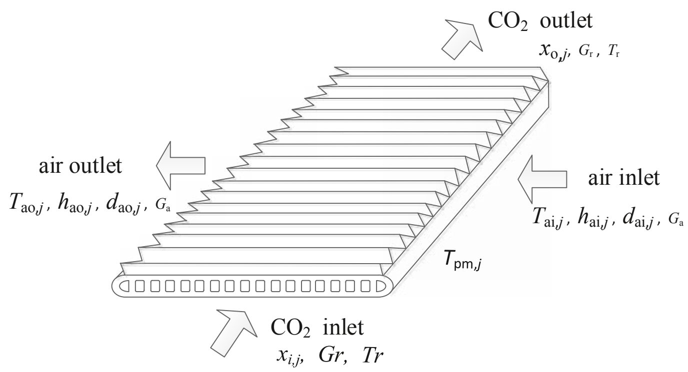

Figure 4. The figure of control volume.

Heat transfer between air and pipe wall under dry and wet conditions:

$$Q_{a,j} = \alpha_{ad}\eta_{ad}A_{a,j}\left(T_{am,j} - T_{pm,j}\right) \tag{4}$$

$$Q_{a,j} = \beta_{aw}\eta_{aw}A_{a,j}\left(h_{am,j} - h_{s,wm,j}\right) \tag{5}$$

Where α represent sensible heat transfer coefficient (W/m²·k), β the mass transfer coefficient (kg/m²·s), η the cooling efficiency, A the heat transfer area (m²), and T the temperature(K).

Where subscript abbreviation: d represents dry air, w the water film, m average, and s saturated.

D. Simulation process design

The heat transfer existing both in two-phase region and overheated region in normal heat pump system, because a certain overheated degree at evaporator outlet is usually required in order to ensure CO_2 enter into the compressor with gas phase. In this condition, the point with dryness equal 1 of CO_2 was calculated first to divide the heat transfer process into the two-phase region and the overheated region. The specific calculation process is shown in **Figure 5**, in which the state parameters of CO_2 and air were obtained from MATLAB by manipulating the REFPROP.

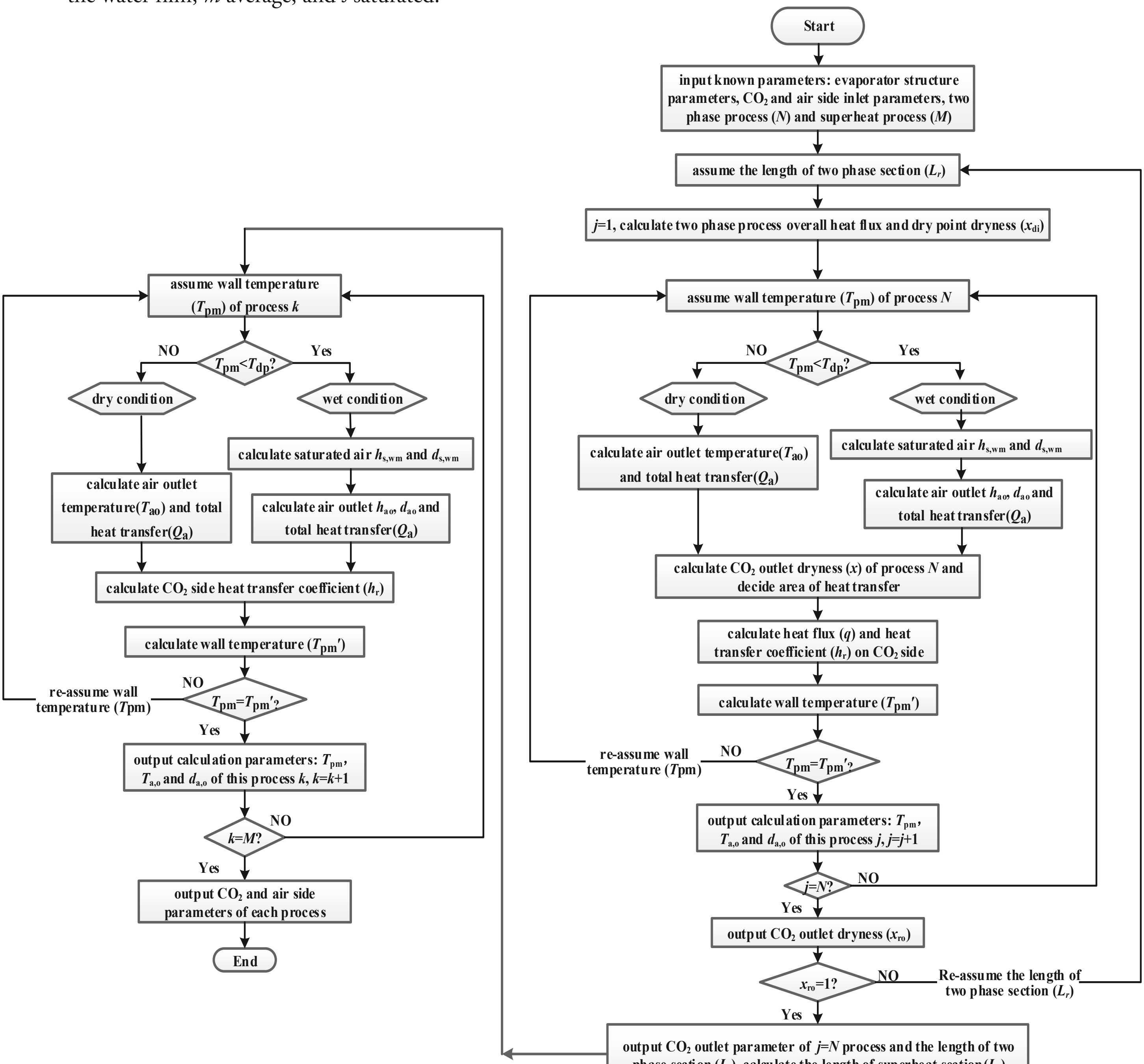

Figure 5. Simulation process of heat transfer.

II. Results and Discussion

A. Comparison of experimental and simulation results

Comparison between simulating and experimental values of CO_2 temperature, tube wall temperature, air inlet and outlet temperature and the convective heat transfer coefficient are respectively shown in **Figure 6** and **Figure 7**.

The relative errors between experimental and simulated values were calculated. The relative error of CO_2

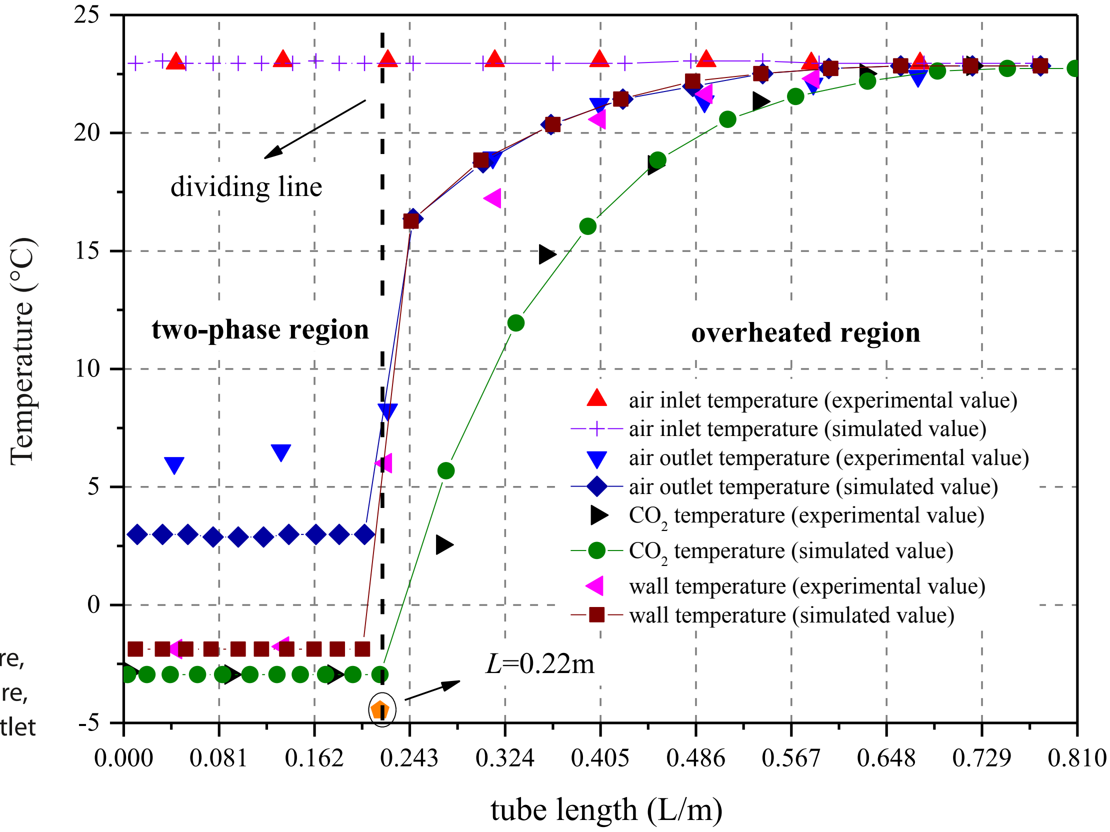

Figure 6. Comparison of CO_2 temperature, wall temperature, air inlet and outlet temperatures.

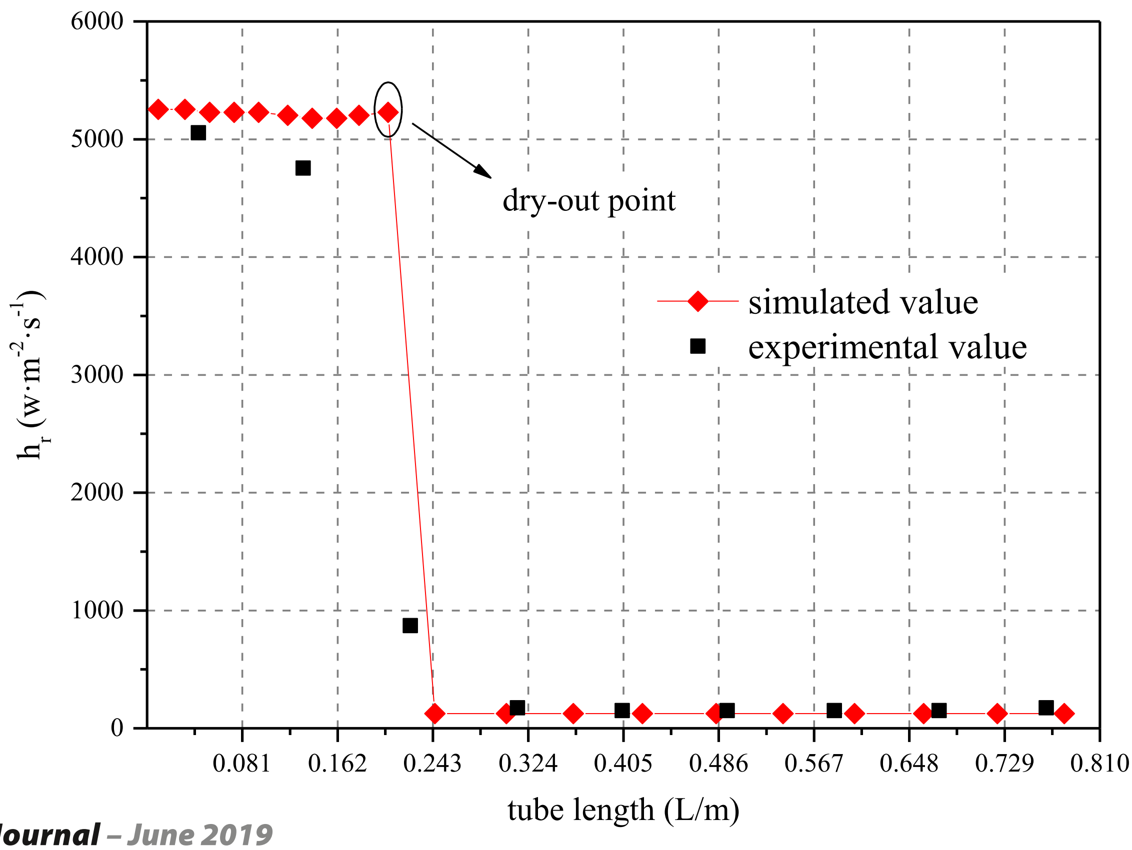

Figure 7. Comparison of the convection heat transfer coefficient.

temperature and wall temperature is under 10%. But the relative error of convective heat transfer coefficient is about 18%. This is because that microchannel evaporator tended to have an uneven flow distribution problem during actual operation which was omitted in the model. Which may cause too much or less CO_2 mass flow rate in some microchannes. Meanwhile, similar changing trend of simulated and experimental values can be seen from **Figure** 7 with acceptable errors range, which is usually 20% for a simulation of engineering application. So the simulation model is highly reliable forfurther analysis and optimization.

B. Sturctural optimization

Considering that the location of the drying point is at the first 1/4 length in the channel as is shown in **Figure** 7, heat transfer efficiency decreases sharply at the latter part of the channel. Therefore, we divide the former one evaporator into two ones with a gas-liquid separator installed between them. The length of the first evaporator is halved to 0.405 m, together with halved flat tubes number of 18. Simulation results show a dryness of 0.68 at the outlet, as is shown in **Figure 8**. Then the two-phase flow of the first evaporator flows into the gas-liquid separator before it enters the compressor. And the remaining 32% liquid refrigerant enters the next evaporator which also has the length of 0.405m. Different number of flat tubes of the second evaporator have been simulated which are 18, 13, 9 and 5 respectively in order to study their impact on heat transfer efficiency under the same inlet air parameters of former experiments, while the CO_2 inlet dryness is assumed to be 0 in the second-stage evaporator.

Figure 9 shows that when flat tubes number is decreased to 9, CO_2 at the outlet of the second stage evaporator is in the overheat zone with over-heat temperature of 6°C as is shown in **Figure 10**. When the number decreased to 5, it turned into two-phase zone. Considering only the postpone of dry-out point, in order to ensure the over-heated state at the outlet, the number of flat tubes should be 9 for optimization of the secondary evaporator, which can reduce the heat transfer area to 37.5% of the original one. Former heat transfer capacity of the evaporator was 3.46 kW, and after the optimization, it has become 2.48 kW for the first stage evaporator, and 0.65 kW for the second stage evaporator, which adds to 90.5% of the former one.

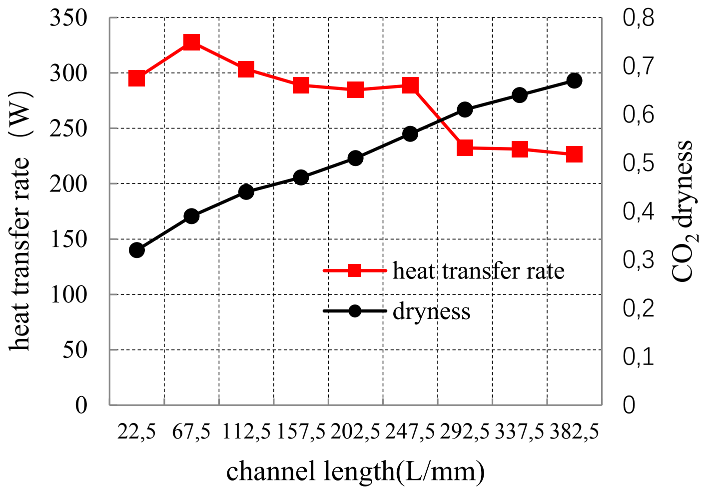

Figure 8. Heat transfer along channel of first-stage evaporator.

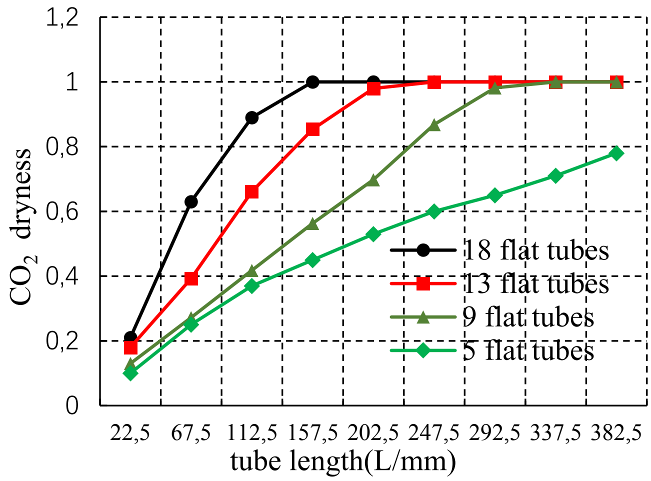

Figure 9. CO_2 dryness of second-stage evaporator under different flat tubes number.

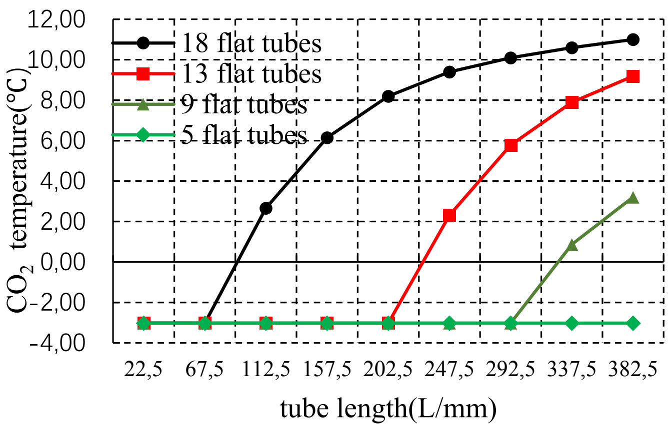

Figure 10. CO_2 temperature of second-stage evaporator under different flat tubes number.

C. Simulation analysis

In order to further reduce the size of evaporator, we plan to figure out the proper operation conditions in which the outlet CO_2 will be in the overheated zone. for evaporator with less flat tubes. Different inlet air temperature, humidity and velocity have been analyzed through simulation for studying their impact on such smaller evaporators as is shown in **Table 4**. Heat transfer rate in each interval was calculated for securing the location of dry-out point. **Figure 11 to 13** showed the impact of inlet air parameters on heat transfer performance:

Table 4. Research conditions.

Category	Air inlet temp (°C)	Relative humidity (%)	Air face velocity (m/s)
Figure 12	23~38	25	2
Figure 13	23	25~70	2
Figure 14	23	25	2~5

We can see the same pattern in heat transfer rate which is similar to former device that the dry-out point marks a threshold of a drastic decline of heat transfer rate after it. While under all inlet conditions, total heat transfer rate remains to be about 600 W. **Figure 12 and 13** show that when air temperature and humidity increase, dry out happens earlier. But the increase of velocity may also improve total heat transfer rate Moreover, air temperature has more significant effect than humidity on the location of dry-out point. Therefore, in order to create a proper condition for smaller evaporator like this in order to have better heat transfer performance, we found that under air temperature of 28°C, humidity of 40% and velocity of 5 m/s, CO_2 can reach the dry-out point in the evaporator with 5 flat tubes with overheated CO_2 at the outlet.

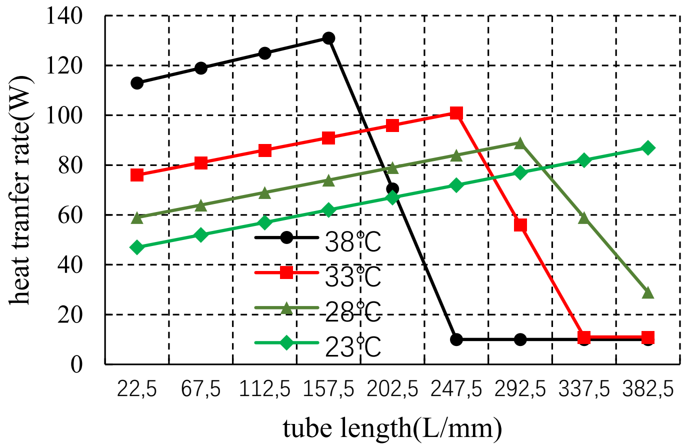

Figure 11. Influence of air temperature on the heat transfer rate.

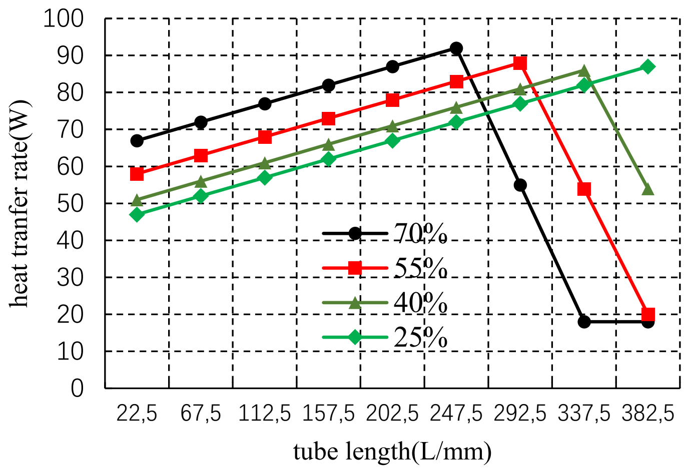

Figure 12. Influence of air relative humidity on the heat transfer rate.

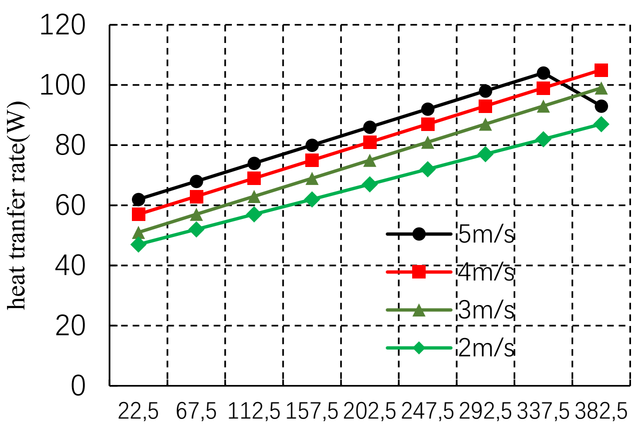

Figure 13. Influence of air speed on the heat transfer rate.

Conclusions

Considering dry and wet conditions on air side and different heat transfer characteristics of CO_2 in two-phase and overheated region, a distributed parameter simulation model of the CO_2 microchannel evaporator was established. The heat transfer in the two-phase region was calculated by Cheng correlation, while in overheated region, it was selected according to the Reynolds number. Comparison between experimental and simulated values in terms of CO_2 temperature, wall temperature, inlet and outlet air temperature and convective heat transfer coefficient showed little discrepancy which verifies the simulation. Both inlet parameters impact on heat transfer performance and structural optimization have been realized through simulation process according to which we can dawn the follow conclusions:

1) The comparison between experimental and simulation results shows little discrepancy within 18% which verifies the simulation method.
2) Convective heat transfer coefficient reached the maximum at the dry-out point and then decline drastically which causes heat transfer deterioration. In the overheated region, the heat transfer coefficient is way smaller compared to that of the two-phase region. Therefore, the later the dry-out happens, the better the cooling efficiency of the device.
3) Structural improvement of the evaporator has been made by separating one evaporator into two with gas-liquid separator between them. Results show that 37.5% area of the original experimental device can still achieve 90.5% heat transfer rate of the former one.
4) Dry out occurs in a 5-tube evaporator when the air temperature is 28°C, with humidity of 40% or air velocity of 5 m/s. Higher air temperature or relative humidity makes the dry out happen earlier, while none of which has apparent impact on the total heat transfer. Higher air velocity not only makes the dry-out occurs earlier, but also improves total heat transfer rate. ■

Acknowledgement

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Development of an adaptive aerofoil contour for use as a fan blade

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Keywords: Adaptive aerofoil, axial fan, flow separation, force measurements

Abstract

This article about a master thesis represents a contribution to the development of axial fans with adaptive blade profiles. The adaptive blade profiles should be able to be changed in operation so that high efficiency is achieved not only at the design point, but also in the partial load range of the fan operation. Studies on the effectiveness of such blades are held to reduce the complexity of stationary aerofoils.

The search concludes that aerofoils which have a function of adjusting their angle of attack and the additional function of adapting their profile curvature would be particularly suitable for the use on rotating systems. In order to prove this assessment, force measurements are carried out on two reference profiles and finally are compared with an adaptive aerofoil profile developed for this purpose. For these measurements, a separate test rig was set up and validated, which allows equivalent investigations on dormant aerofoil profiles.

The three profiles were developed according to Carolus and designed for the production with a 3D printer using CAD software.

In the final part, investigations are carried out with a laser-optical measuring method in order to reveal potential for improvement in future research.

With an overall assessment of the effect of the adaptive aerofoil, as well as a recommendation for the use of the potentials, this work contributes to the further development of axial fans with adaptive blade profiles.

This article is the winner of REHVA Student Competition award, see news on page 90.

I. Introduction

A. Basics about fans

Fans are flow machines designed to transport gaseous fluids. They are often used in recooling systems or decentralised ventilation systems. Also, for special applications such as mine ventilation or in wind tunnels, axial fans are used because of their performance in the transport of large volume flows [4]. The task of mass transport fans should meet with a certain volume flow at a given pressure difference. This design point is regularly used to define the type of flow machines. When designing building services, it is common practice to design the fans to peak performance with an additional safety margin to ensure building operation at full capacity. However, it is realistic that the facilities will not work at the design point but mainly in a part load operation. Manufacturer of fans take this into account and therefore develop the blades of a fan in their shape so that they work not at the design point, but at a certain load point with maximum efficiency [6]. However, high efficiency would not be desirable in points, but over a load range between the part load and the design point.

In addition to business economic motivation, environmental policy also plays a role in the design of fans. For example, following the identification of a significant potential for improving the environmental impact of energy-related products, the European Commission also adopted a regulation on the environmentally sound design of fans. Since the regulation (EU) Nr. 327/2011 came into effect, the requirements on the environmentally sound design of fans are according to the directive 2009/125/EG lawfully defined [2]. With a measured system efficiency, axial fans with a power consumption of 125 W ≤ P_{el} ≤ 10 kW currently has to meet a target efficiency is given by equation (1) with

$$\eta_{target} = 2{,}74 \ln(P) - 6{,}33 + N \qquad (1)$$

where P is the electrical power consumption in kW and N is a prescribed degree of efficiency (static N = 40).

The efficiency tests take place on standardised test setups, whereby the data is recorded with optimal efficiency [2].

It is conceivable that such static test methods will be replaced by methods with dynamic load distribution in the future and thus the target efficiency must be met not at an optimal point, but in different ranges. If the efficiency requirements for fans continue to rise in the future, then the research on fan blades with adjustable curvature while running will be not only very useful, but also an important step in the development of a more efficient generation of flow machines.

This work contributes to the development of adjustable blade contours for use in axial fans. The focus of the work is the development of an adjustable blade and the proof of an improvement of partial load behaviour. For this, a test setup must be developed and verified. Corresponding examinations and test series should prove the effectiveness of the adjustable blade.

B. Working principle of fan blades

"Everybody moving in a fluid experiences a force. Of interest are those bodies which - in addition to a low drag force against the direction of movement - have a high lift force perpendicular to the direction of movement. Planar bodies with these properties, whose dimensions in one direction - the "thickness" of the body - are much smaller than in the two perpendicular directions - the "depth" and the "span" - are called "aerofoils". A section perpendicular to the span direction may be called "aerofoil profile" or "profile" for short." [10].

During the flow around a profile, different speed and pressure conditions occur along its surface. The air is accelerated when displaced, the dynamic pressure increases, and the static pressure decreases according to the energy conservation. The pressure field along the surface is therefore crucial for the resulting lift force.

Fan blades operate on the principle of an aerofoil and typically have an asymmetric curvature. The force resulting from the pressure gradients expresses as lift force on the blades which is necessary for the transportation of the fluid. The one-sided curvature generates a drop in static pressure in front of the fan. A good aerofoil contour is characterised by high lift force with low drag force.

The glide ratio

$$\varepsilon = \frac{W}{A} \; , \qquad (2)$$

is an indicator for the rating of different contours. The thickening of profiles as well as the increase of its curvature results in an unfavourable glide ratio [5].

C. Fan-characteristics

The flow properties of fans are described with fancharacteristics. These describe the possible operating points of a fan from free-air point ($\dot{V} = max$, $\Delta p = 0$) to stagnation point ($\dot{V} = 0$, $\Delta p = max$) at a specific speed. **Figure 1** shows a schematic fan-characteristic with loss fractions where the operating point is optimally located at the point of least loss. Often only the static pressures without losses are indicated in the fan characteristics.

For an optimal operation of fans, the sum of hydraulic losses Z_h must be minimised through a net-adapted blade configuration on the impeller. The impellers work Y_{Sch} then transfers to the fluid as much as possible.

$$Y = Y_{Sch} - Z_h = \frac{\Delta p_t}{\rho} \quad (3)$$

It is:

Y = the spec. Nozzle-work (between suction and discharge nozzles)

Y_{Sch} = the mass-specific work by the fan blades

Z_h = the sum of the hydraulic losses

Δp_t = the increase of total pressure [9]

Unlike fan-characteristics, system characteristic curves describe the resistance to be overcome for transporting fluids generated by friction in the network. Each fluid system has a characteristic which, with

$$\Delta p = \frac{\rho}{2} v^2 \quad (4)$$

is a quadratic function of velocity. The intersection of the fan characteristic with the line characteristic is the operating point.

A change in the system characteristic can, for example, by actuation of a throttle damper, but also caused by contamination. The connection between the volume flow and the necessary support work in the fluid system then changes and new operating points are created.

Figure 2 shows the fan-characteristic of an axial fan according to BANZHAF [3] at a constant speed and a constant blade angle in a system with a continuously closing throttle damper. With an opened throttle, the fan works at operation point (1) with low pressure loss and high volume flow. With increasing throttling, the operating point on the fan characteristic rises above (2) and (3) to point (4). At point (5) the fan works with maximum pressure increase on the stable part of its characteristic curve. With further throttling the flow separates from the fan blades and the pressure increase suddenly drops. In order to return the fan from the unstable characteristic curve at point (7) to the stable characteristic curve, the throttle must be opened until point (8) has been reached. Only from (9), the flow again can be close on the blades, whereby the fan changes back into its stable characteristic range.

Instable operating areas of the axial fan lead to socalled pumping which causes an increased oscillatory load. This manifest itself in acoustic problems, damage to the duct system or damage to the suspension, bearings and blades of the fan [3].

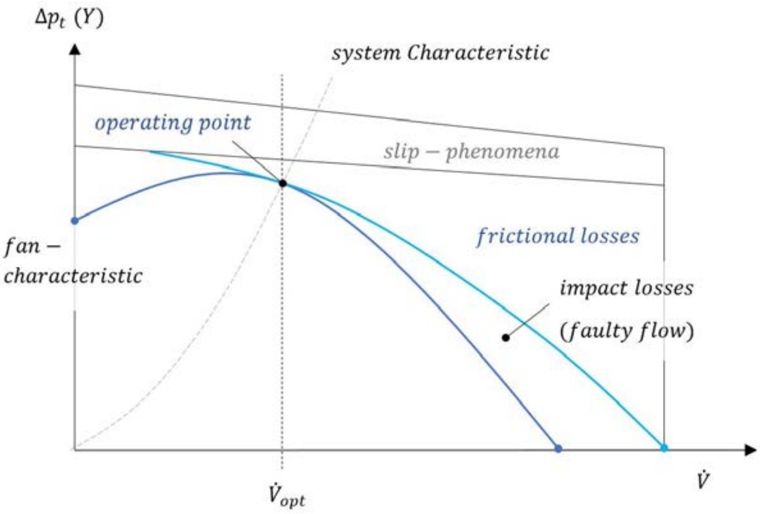


Figure 1. Volume flow total pressure characteristic diagram [7]

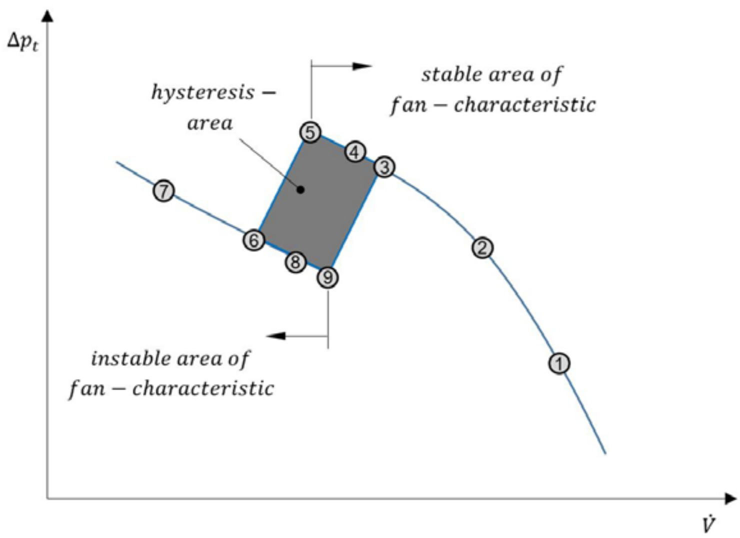


Figure 2. Characteristic of an axial fan [3]; Rotational speed: n = const.; Impeller blade angle: β_s = const.

D. Cause of flow separation

Figure 3 shows the profile section of an impeller blade with its velocity triangles at the operating points (1), (2) and (6) from **Figure 2**. It is recognisable that the velocity component $\boldsymbol{c_1}$, which describes the volume flow though the fan decreases as result of a change in the system characteristic; this can be caused by throttling.

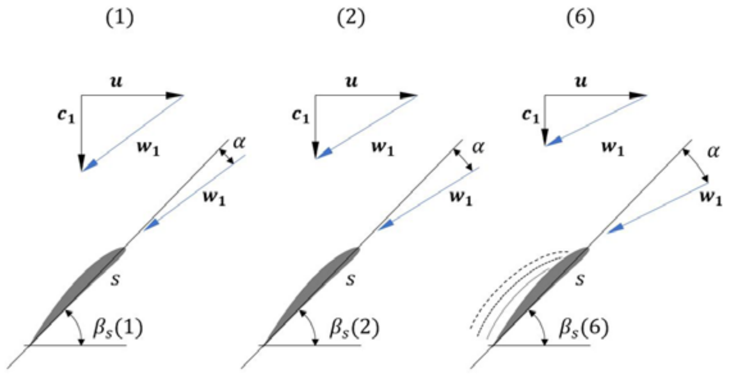
The size of the angle of attack α on the profile nose particularly influences the flow pattern on the aerofoils suction surface. If α has a favourable size according to the design of the profile, the air can overflow the profile with low impact. With increasing the angle of attack, it comes first to increase of lift force, but at the expense of worsening the glide ratio. If a maximum value of α is exceeded, the flow on the suction surface separates, which leads to a sudden drop in lift forces and a considerable deterioration in the gliding ratio [3].

Figure 5 shows a brief representation of the characteristics of a system with variable resistance and the characteristics of a fan with variable blade angles. By adjusting the angle of attack of the fan blades, different operating points can be achieved. If the fan design is correct, the operating points are in the range of high efficiency [3].

When changing the blade angle, the shape of the fan blade is disregarded. The shape of the optimum blade profile depends on the operating point of the fan with the required size volume flow, pressure difference and speed. Usually, this blade profile is not changeable and is picked out for the design point.

As a result, after an adjustment of the angle of attack, the velocity and direction of the flow is less favourable for fan blades with a good glide ratio. The buckle of the blade is then unfavourable because it is not operated at its design point. This produces air impact losses, thereby degrading efficiency and also giving rise to flow separation earlier. An adaptation of the blade profile is therefore crucial for a high efficiency.

Fans with adjustable blade angles are already well developed, but are rarely used because of the complexity and low advantages over speed control [12].



$$\beta_s(1) = \beta_s(2) = \beta_s(6)$$

$$\boldsymbol{u}(1) = \boldsymbol{u}(2) = \boldsymbol{u}(6)$$

Figure 3. Flow triangles at the Impeller [3]

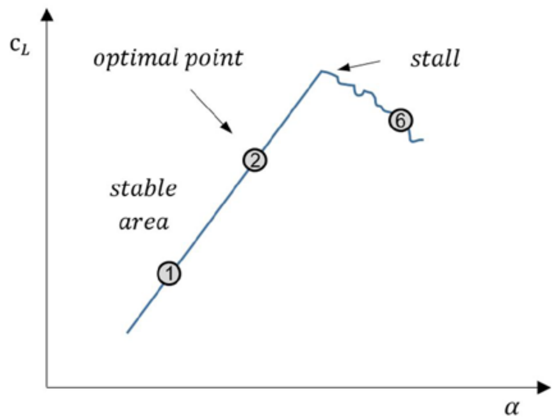
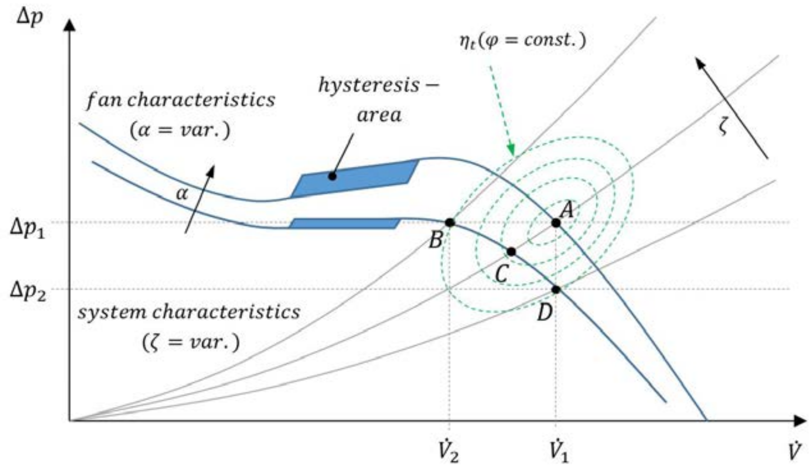


Figure 4. Lift polar schematically according to **Figure 2** [3]



A→B: Δp = const, $\dot{V}_2 < \dot{V}_1$

A→C: ζ = const, $\dot{V}_2 < \dot{V}_B < \dot{V}_1$, $\Delta p_2 < \Delta p_B < \Delta p_1$

A→D: $\dot{V}$ = const, $\Delta p_2 < \Delta p_1$

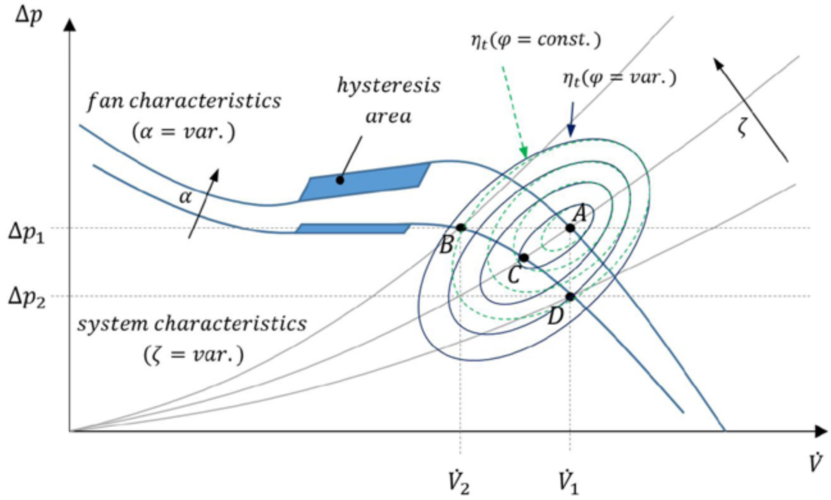
Figure 5. Characteristic diagram with variable impeller blade angles [3].

If this blade angle adjustment succeeds in completing a camber adjustment function, the range of high efficiency can be significantly extended. The aim here is to control the adjustment of the profile curvature so that, depending on air speed, pressure and rotational speed, an increase of the range is achieved with high efficiency.

The aim is therefore the development of blades with adjustable blade angle, which have an additional function to change their profile curvature. In **Figure 6**, the improvement is shown schematically.

In order to produce different contours as faithfully as possible with an adaptive aerofoil, a specific subdivision of a profile (4-digit series NACA 4410 [1]) was applied by the superimposition of the parabolic arcs calculated for the construction. It turned out that in the division with three cuts, the shapes of different profiles can be simulated in a favourable approximation (**Figure 7**). The designed aerofoil consists of four parts, produced by a 3D printing process, which are connected to a common axis. To seal the resulting gaps on the surface of the aerofoil it has been covered with a nitryl-membrane.

All asymmetrically curved profile shapes have an optimal angle of attack with low impact losses. This corresponds to the $\boldsymbol{w_1}$ at a design-dependent profile curvature. With a mechanical drive, the curvature of the aerofoil adapts itself to its angle of attack, thereby eliminating the increase in the profile angle α with increased work requirements (**Figure 8**).



A→B: Δp = const, $\dot{V}_2 < \dot{V}_1$

A→C: ζ = const, $\dot{V}_2 < \dot{V}_B < \dot{V}_1$, $\Delta p_2 < \Delta p_B < \Delta p_1$

A→D: $\dot{V}$ = const, $\Delta p_2 < \Delta p_1$

Figure 6. Characteristic diagram schematically [3], extended with a variable blade camber $\varphi(\alpha)$ = var.

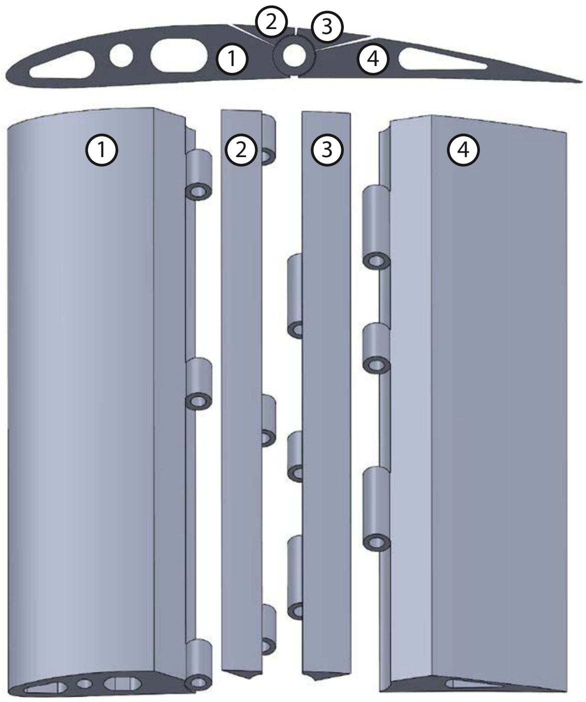


Figure 7. Idea for the construction of an adaptive aerofoil.

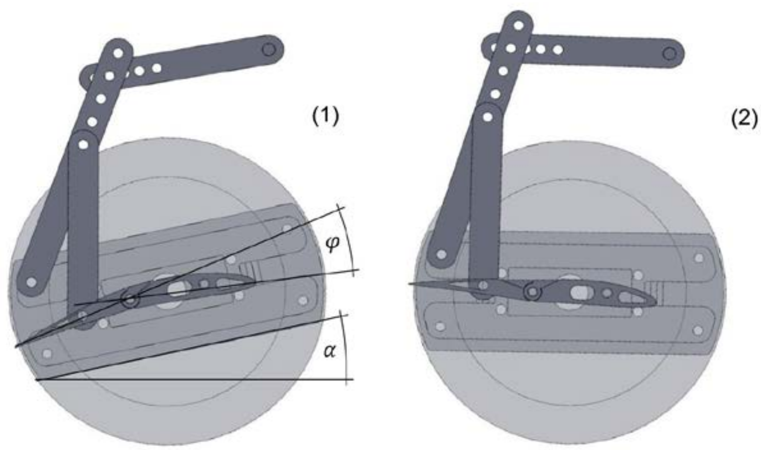


Figure 8. Working principle of adaptive camber drive ($\alpha_1 > \alpha_2$, $\varphi_1 > \varphi_2$).

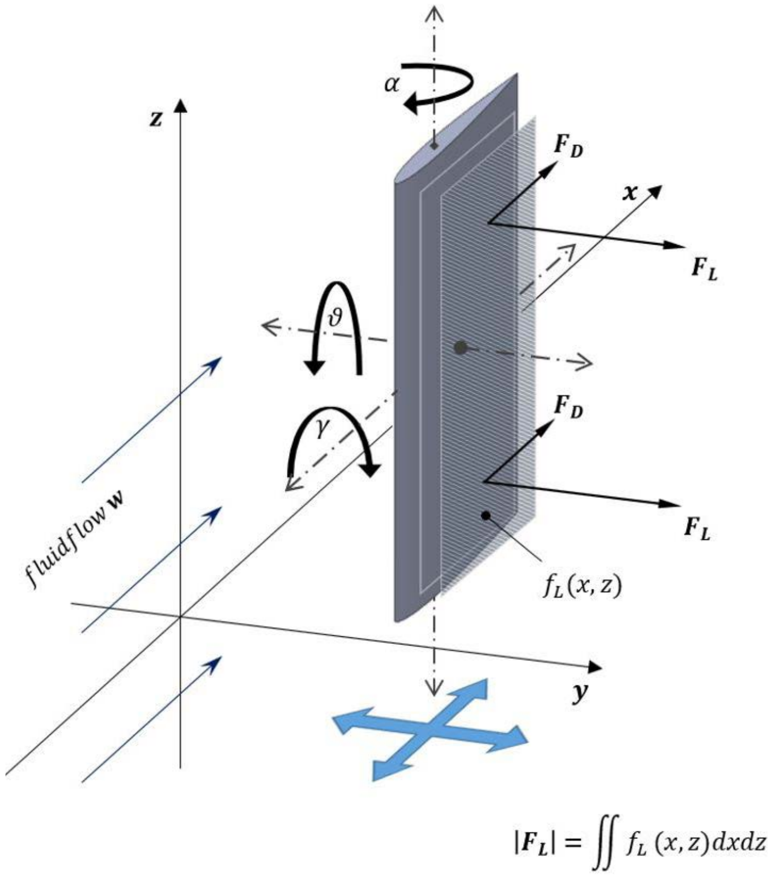


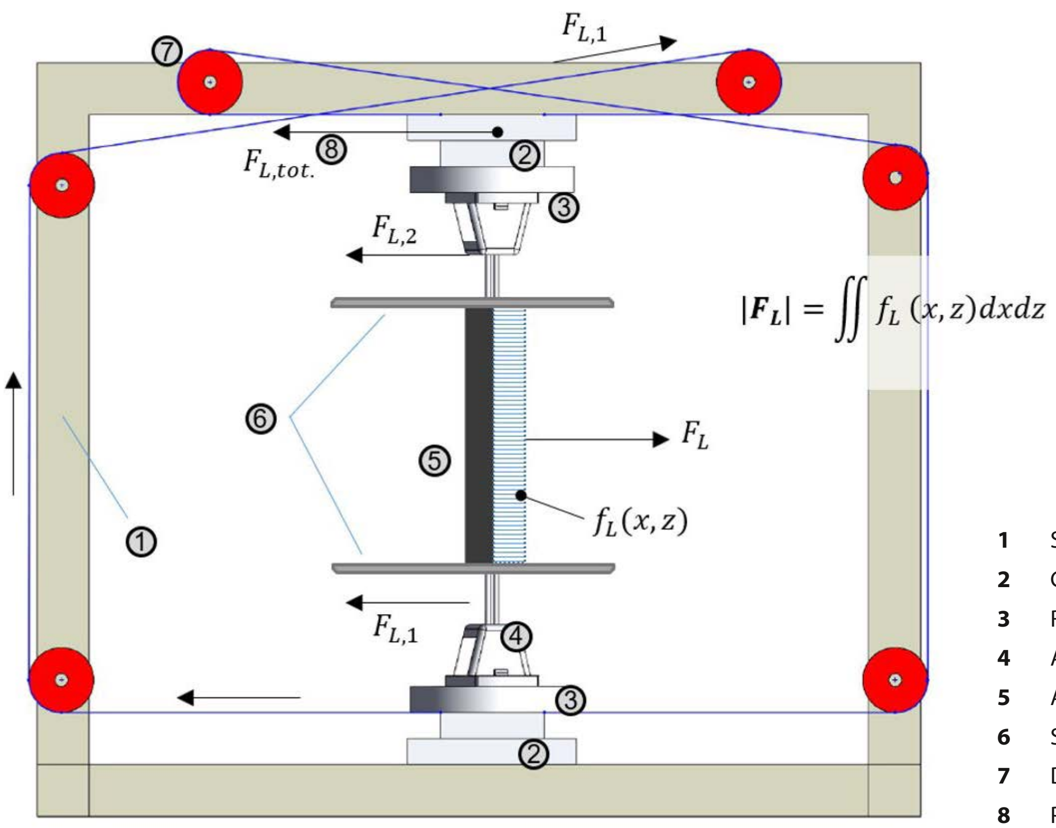
Figure 9. Representation of forces and degrees of freedom.

II. Experimental investigations

A. Measurement method

For the measurement of optimal lift-forces, which are determined by minimum values of the glide ratio ε, a test rig was developed. During the development of the test rig, six degrees of freedom of bodies in space were considered. These are the three coordinates of the body's centre of mass x, y, z, as well as the associated angles in space $\gamma, \vartheta, \alpha$ [11]. **Figure 9** shows an aerofoil in dimetric exposition with the axial, rotational and pitching forces.

If aerofoils are examined by force measurement in wind tunnels, often one end of the aerofoil, similar to an airplane, is free in the flow. To account for these moments in the measurements, the aerofoil was attached at both ends, eliminating γ and ϑ. At the attachments of the aerofoil, a pair of forces then act accordingly to the priority of $|F_L|$ and $|F_D|$ (**Figure 10**). Side forces acting in the z-direction will be eliminated through the aerofoil's orientation when the leading edge of the aerofoil is orthogonal to w. Through the setting, the angle of attack α is fixed. The elimination of the degrees of freedom $\alpha, \gamma, \vartheta$ and z, permits force exclusively on the measurement plane $x-y$, which are captured as lift and drag forces.



1	Stand
2	Gliding carriage
3	Rotary plate
4	Aerofoil attachment
5	Aerofoil
6	Side plates
7	Deflection roll
8	Position load cell

Figure 10. working principle test setup where $F_{L,tot} = |F_{L,1}|+|F_{L,2}|$.

B. Force measurements

Figure 11 shows the measured polars–F_L/α of the three aerofoils A (4410 rigid), B (2410 rigid) und C ([2-4]410 adaptive).

The light blue line in the graph describes the polar of the adaptive aerofoil C. Unlike the polars of the rigid aerofoils, which have a slight right curvature, the polar of the adaptive aerofoil having a relatively constant shape over the angle of attack passes.

Under the angles of attack of $1.5° \leq \alpha \leq 8°$ aerofoil C develops the same lift values as B. At values $1.5° \leq \alpha \leq 8°$, the polar runs between A and B and intersects A at $\alpha \approx 12°$. With a further increase in the angle of attack up to $\alpha \approx 20°$ the lift force increases to 10 N and remains at this value. Only at an angle of $\alpha \geq 25°$ is a very sudden drop in the lift observed.

The polars that can be seen in **Figure 12** show the lift values over the associated drag forces. Using a polar tangent through the origin, minimum values for the glide ratio ε can be indicated. Aerofoil A is therefore more efficient for larger lift forces, for smaller B is favourable.

The polar of aerofoil C is less curved than that of A and B, begins with the first reading at 1.2 N lift force, 0.4 N drag force and runs below the polar A and B. Before the decline of the lift value, a plateau at a force of 10 N can be recognised. It can be seen from the diagram that the drag values of the adaptive aerofoil C are higher than those of the rigid profiles.

C. PIV-measurements

For numbering the velocity of flow as well as for the detection of flow separation, the measurements at the adaptive aerofoil were extended with PIV analysis. The measurements also allow an additional assessment of the effects of the nitryl membrane on the surface flow.

Figure 13 shows the aerofoil under the angle of attack of $\alpha = 12.4°$ and the related camber of $\varphi = 20.9°$. The measurements

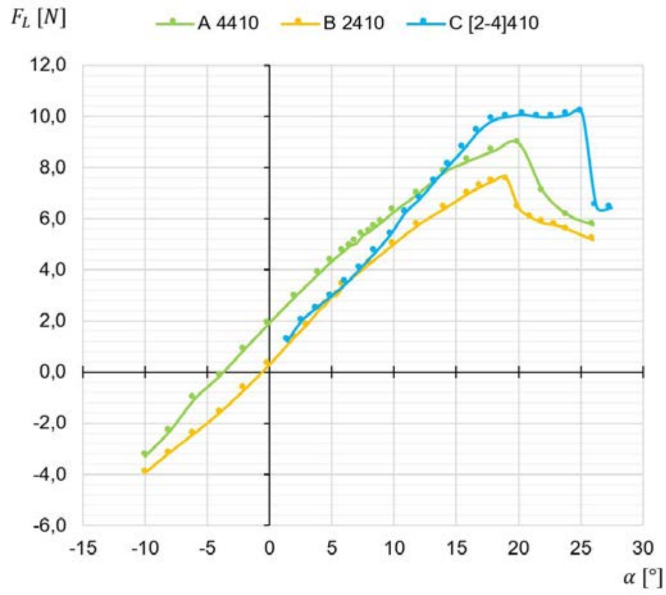


Figure 11. polars–F_L/α.

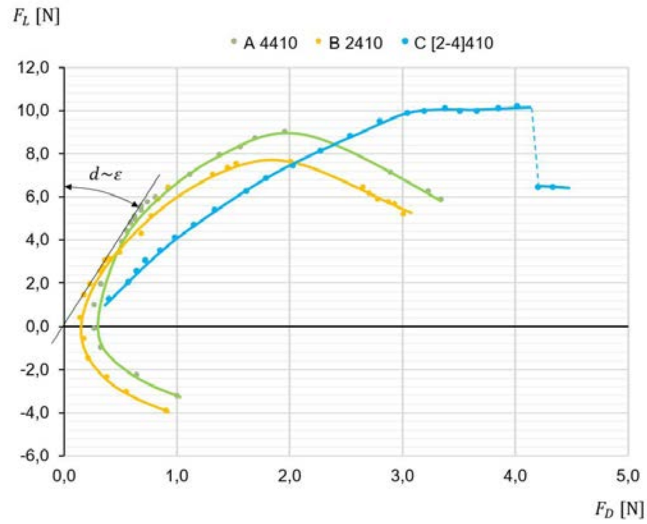


Figure 12. polars–F_L/F_D.

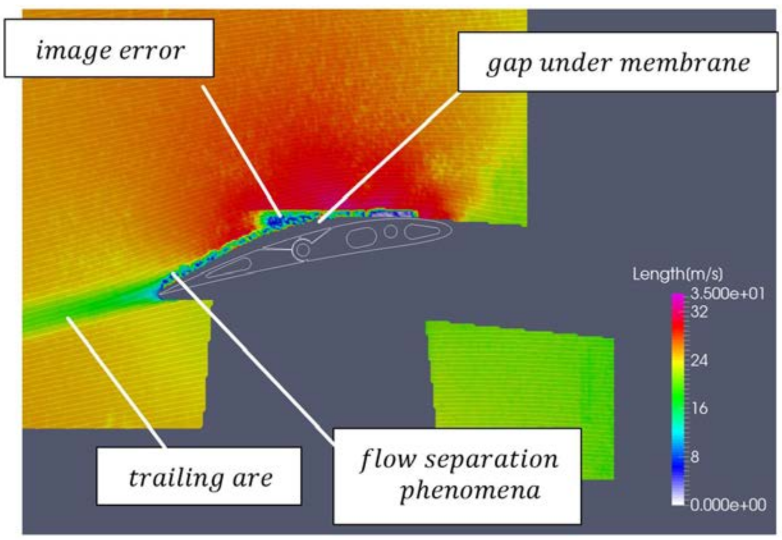


Figure 13. PIV flow mapping $\alpha = 12{,}4°$; $\varphi = 20{,}9°$.

showed that the stall-phenomena does not lead to flow separation despite an increased camber. The field of high velocities that increases at the leading edge and decreases glidingly with trailing edge indicates a favourable flow. Furthermore, a gap between aerofoil and air can be seen. The cause is that the surface rises due to the suction pressure, which increases the geometric thickness of the profile and can be seen as the reason for the increased drag forces according to **Figure 12**. Whether this has an influence on the lift distribution in addition to the increase in the form resistance, this must be investigated by future reference measurements.

Air velocities greater than 30 m / s can be detected near the suction surface at an incoming freestream velocity of 20 m/s.

III. Conclusion

The development of auto adaptive aerofoils for the use as a fan blade will improve the efficiency of flow machines.

It has been shown, that an aerofoil with a variable camber achieves an improved lift characteristic, especially at requirements outside the design point. This was proven by force measurements.

A high priority in the development of such adaptive aerofoils must be the preservation of a streamlined profile shape with all adjustable cambers. Investigations in the last century have produced many profile shapes, which have been extensively studied, described and optimised for the smallest values of ε. These forms are subject to a calculation method for defining a favourably curved skeleton line. In the adaptive aerofoil constructed in this work, the family of four-digit NACA profiles were chosen. The uniformly gentle curvature of the skeleton line, which is desired during the change in curvature, is shifted by a division into sections with a common point of rotation. The change in the curvature is transferred as a superposition to the skeleton line as **Figure 14** shows.

It can therefore be summarised that for the successful construction of an adaptive aerofoil, a low resistance through the flow-optimised contour and a high surface quality are decisive.

Which of the listed criteria outweighs and which effects the simulation of different cambers compared to the rigid original contours, on drag and lift forces, must show a number of further investigations. However, it is advisable to first investigate the effects of different surface materials on the drag forces on the aerofoil.

A. Outlook

The development of a seal for the surface of the adaptive aerofoil with less disruptive effects, for example with the help of a silicone joint or with a perforated membrane, should be strived for further research.

If it were possible to design the surface and shape of the adaptive aerofoil so that the drag force would be similar to that of A and B, the polar–F_L/F_D could look

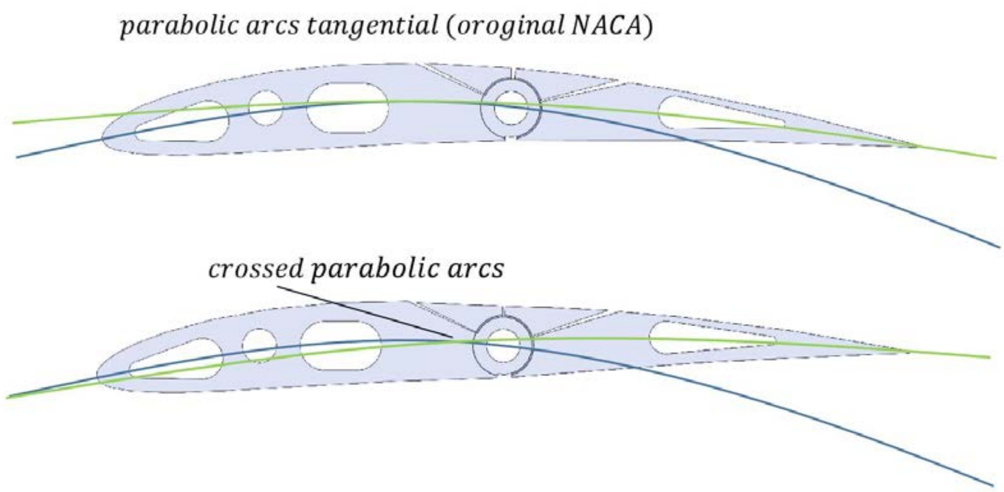


Figure 14. Superposition of the skeleton line.

like **Figure 15** and achieve optimum values for ε over large areas of F_L.

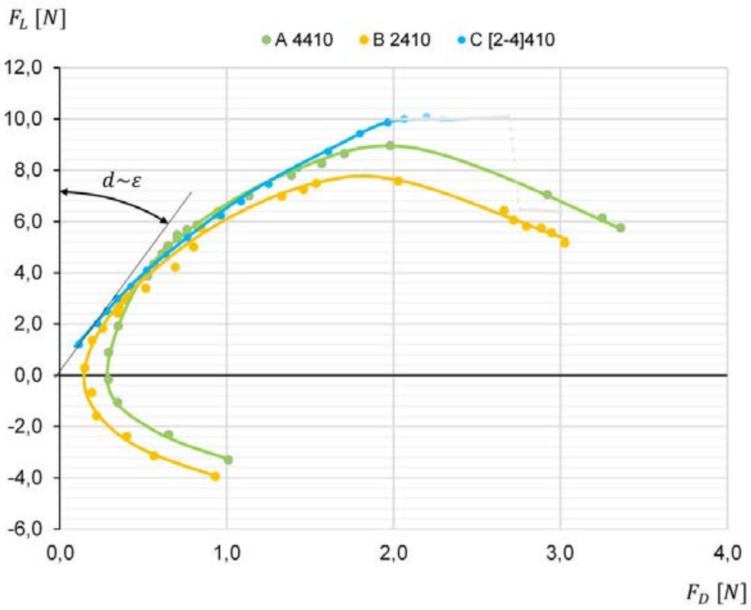


Figure 15. theoretic polar.

In the future, acoustic measuring tools for controlling the curvature of impeller blades would be conceivable in order to guide fans on the stable part of the fan characteristic curve. The development of innovative materials, such as shape memory alloy metals or advances in the applicability of elastomers could be an important part of fan design in the future. A replacement of complex mechanisms in the impeller would be conceivable [8].

Concluding remark

The research on adaptive aerofoils opens up great potential for the energy-saving use of axial fans. The upcoming challenge is the development of a suitable drive for the required camber control and its integration into the impeller blades.

This would be a large-scale success for a new generation of turbomachinery with dynamic characteristics. ■

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Predicting personal thermal preferences based on data-driven methods

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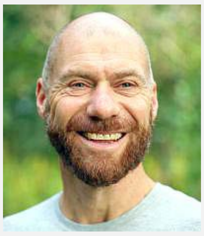

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Abstract

Personal Comfort Models (PCM) is a data-driven approach to model thermal comfort at an individual level. It takes advantage of concepts such as machine learning and Internet of Things (IoT), combining feedback from occupants and local thermal environment measurements. The framework presented in this paper evaluates the performance of PCM and PMV regarding the prediction of personal thermal preferences. Air temperature and relative humidity measurements were combined with thermal preference votes obtained from a field study. This data was used to train three machine learning methods focused on PCM: Artificial Neural Network (ANN), Naive-Bayes (NB) and Fuzzy Logic (FL); comparing them with a PMV-based algorithm. The results showed that all methods had a better overall performance than guessing randomly the thermal preferences votes. In addition, there was not a difference between the performance of the PCM and PMV-based algorithms. Finally, the PMV-based method predicted well thermal preferences of individuals, having a 70% probability of predicting them correctly.

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José Joaquin Aguilera received the DAIKIN Award for the best poster at the CLIMA 2019 HVAC World Congress 29th of May 2019 in Bucharest.

1 Introduction

The prevalent approach for design of thermal comfort in HVAC systems worldwide is based on the Predicted Mean Vote (PMV) model [1, 2]. This model predicts the overall thermal sensation of occupants, based on two personal parameters: metabolic rate, clothing level; and four environmental variables: relative humidity, mean radiant temperature, air temperature and air velocity. However, the method requires data that is difficult to estimate in real applications, such as: metabolic activity rate and clothing level. In addition, the PMV is not able to re-learn from new data since the input parameters it uses are fixed in the model. Lastly, the model had a poor predictability performance when applied to individuals in some field studies [3-5]. In the last years, a new approach to model thermal comfort has been suggested, taking advantage of modern data modelling techniques, named Personal Comfort Models (PCM). They take individuals as units of analysis, where measured data is combined with feedback from occupants to create models that predict individual responses [6]. PCM are based on data that is easy-to-obtain and cost-effective, using machine learning algorithms for data processing. Different algorithms and sources of information can be used, adding flexibility to the data modelling.

The framework described in this report evaluates the performance of three different machine learning techniques and compares them with an algorithm grounded on the PMV model. Data obtained from a participatory sensing assessment in two university offices was used to compare all the methods in terms of the prediction of thermal preference votes. This project contributes with the following: (1) A field evaluation of a thermal comfort web-based survey, (2) A performance evaluation of four methods: Artificial Neural Networks (ANN), Naive-Bayes (NB), Fuzzy Logic (FL) and Predicted Mean Vote (PMV) with regards to thermal preference predictability.

2 Related work

Different approaches to model thermal comfort at a personal level have been made in recent years. Many of the initial attempts originated from multidisciplinary efforts rather than thermal comfort research alone. A number of those studies used the PMV index as the metric to integrate thermal comfort in learning algorithms [7–10]. All of them employed a multi-valued logic called fuzzy logic to characterize different thermal comfort categories given by the PMV. This approach has the limitations of the PMV model: the difficulty to account for personal parameters and is not focused on individuals. As a result, there is a growing interest to develop methods that employ data easy and cheap to measure, taking advantage of state-of-the-art mathematical modelling methods. Different machine learning techniques have been tried depending on the available data and the focus of the method. Bayesian networks was the tool implemented by [11] to model thermal comfort preferences. This framework achieved a 70% accuracy when predicting thermal preference votes from occupants in a field study. The same learning technique was used by [3] to determine comfort temperatures with the ASHRAE RP-884 data base, a set of data used to develop the Adaptive Thermal Comfort Model [12]. The approach showed an improved performance compared to conventional thermal comfort models such as PMV and the Adaptive model. Artificial Neural Networks were implemented by [13] to model thermal sensation. This approach showed 80% accuracy when predicting occupants' votes in a field evaluation.

Despite the above, there has not been many applications of PCM in field studies for long periods. Fuzzy logic controllers were employed by [14, 15] to model thermal preferences from occupants in offices. That information was used together with ventilation airflow measurements to control a HVAC system for a period of 13 and 14 weeks. The results showed 12–39% airflow reduction and an improvement of thermal comfort when using the methods based on fuzzy logic. However, the performance of a participatory sensing methodology relies substantially on the degree of participation of the occupants. Keeping the consistency of occupants' participation is a challenging task. Different types of survey interfaces were tested by [16], proposing a plain slider scale that improves participation and consistency when carrying out a participatory sensing approach.

To avoid relying on occupants' feedback, several investigations were made to find correlations between human behaviour and thermal comfort. A Personal Comfort System (PCS) was applied by [6], consisting of a device that allowed occupants to regulate the temperature in their local working area, using a custom-built seat. Occupants' behaviour when regulating their local thermal environment was combined with surveyed information and thermal environment measurements. This information was used as input to six different PCM-based machine learning algorithms to predict thermal preference votes. The results showed that the PCM had an average prediction accuracy of 73%, which was better than the performance of conventional thermal comfort models, which only had a 53% accuracy.

The implementation of PCM in real HVAC applications is still a developing task. More field studies are needed to test the performance of data-driven methods when predicting personal thermal responses.

3 Methodology

A field assessment based on a field study was carried out in two offices at the Technical University of Denmark. Thermal preference votes from six participants were obtained continuously during a period of thirteen days. Occupants were provided with a web-based survey that could be accessed either by smart-phones or personal computers. During that period, the thermal environment in the room was modified in a non-systematic manner by opening windows, turning on/off electric heaters and controlling water flows inside radiators. Air temperature *Ta* and relative humidity *RH* were recorded periodically every 5 minutes at the local workplace of each occupant by using HOBO-loggers as measuring instruments [17]. This procedure was used to obtain a wide range of thermal preference votes as a result of having different levels of thermal environment inside the offices.

The aim of the evaluation was to characterize the performance of four algorithms when predicting thermal preference categories or classes, generated from the participatory sensing votes. The numerical value of a vote is called Thermal Preference Value (*TPV*), which can take values between 0 and 18. Three different classes were generated from the *TPV* as follows: from 0 to 7 corresponded to "Colder", from 8 to 10 were considered as "No change" and 11 to 18 were considered as "Warmer". A thermal preference category with its corresponding *Ta* and *RH* measurement formed a data point. The total number of data points gathered along the evaluation period was divided into data used for training and testing the learning algorithms. How good the performance of an algorithm was depended on how well it predicted thermal preference classes based on unseen *Ta* and *RH* measurements or testing data. The ratio between training and testing data was optimized in a sensitivity analysis, evaluating the outcome in terms of classification performance. An algorithm that has a good performance of predicting thermal preferences is able to provide an accurate description of occupants' individual comfort zones. Thus, HVAC control systems can benefit from the inclusion of such algorithms to provide an adequate indoor environment, specific for different requirements and working conditions.

3.1. Field study

Occupants were asked to answer a simple question: *How would you prefer the temperature?* The answer was given in a snapping scale, where it was possible to select: much colder, no change, much warmer or any value in between, as shown in **Figure 1** (left). After each vote was made, a graphical feedback was given to every participant, illustrated in **Figure 1** (right). This plot showed the total number of daily votes per category in the room to encourage occupants' continued participation. All six participants were requested to vote as many times as they could. They were provided with daily reminders during the evaluation period. The only restriction for the participants was not to vote with a minimum timespan of 15 minutes between votes. This condition was to avoid having persistent occupants expecting to get a rapid change of their current thermal environment. However, all votes were taken into account in the assessment, no matter the period of time between them. The design of the participatory sensing survey aimed to maintain participation along the evaluation period and improve consistency, according to the findings of [16].

3.2. Algorithms

The methods applied in this study provided a rather intuitive application and did not consider a large number of assumptions with respect to the data used to train them. This allowed implementing the algo-

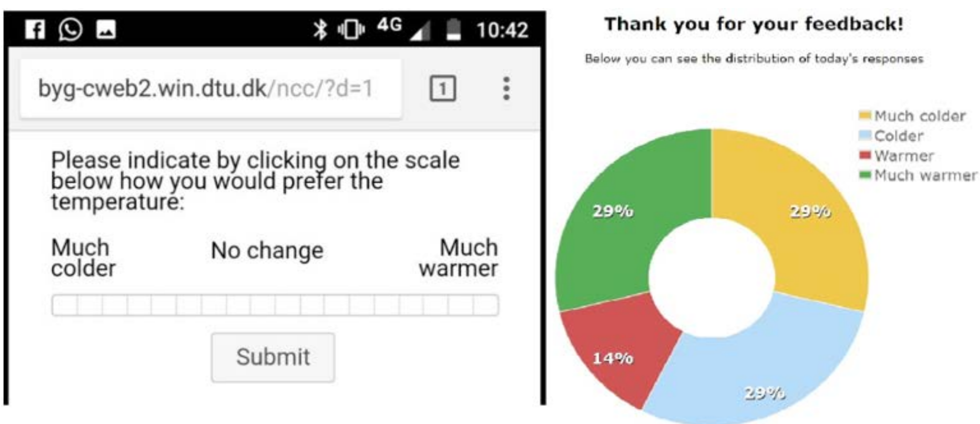

Figure 1. Survey implemented in the field experiment.

rithms without adjusting many parameters, thus, it was straightforward to determine their optimal performance. A brief description of the methods and considerations taken into account are presented as follows:

3.2.1 Artificial Neural Networks (ANN)

ANN is a method used to solve non-linear problems by using a network composed of individual elements or so-called neurons. In each neuron, different types of mathematical transformations or transfer functions are used. The outcome of this technique is a network where the weight of each neuron has been optimized to minimize the error between the output of the network and the data used for training. ANN was implemented by using the Matlab Artificial Network Toolbox. Three different types of transfer functions were tested: Log-Sigmoid (logsig), Hyperbolic-Tangent Sigmoid (tansig) and Linear transformation (purelin). An iterative process was carried out through a method called Levenberg-Marquardt backpropagation (LM-BP) [18].

3.2.2 Naive-Bayes (NB)

The NB method uses the basic principles of probability, based on the application of the Bayes theorem. This states that the probability of a given event is calculated from previous knowledge about conditions related to an event. In particular, the term "naive" comes from the assumption that different factors that affect the event are independent of each other, also named conditional independence. In this method, it is also assumed that all thermal preference categories or classes have the same distribution. To implement this method, first a Probability Density Function (PDF) was selected and applied to the training data, calculating the mean and standard deviation of each parameter. These two statistical parameters were used to calculate the probability of a certain class of unseen data, used for testing [18].

3.2.3 Fuzzy logic (FL)

FL is a multi-valued logic grounded on the statement that the truth of an affirmation is a matter of degree, first introduced by [19]. Unlike in classical logic where a variable can be either 1 or 0, in FL a variable can also be any value in between those numbers. The data in FL is classified as fuzzy sets, which represent linguistic variables (e.g., hot, cold, low or high). How much a data point belongs to a fuzzy set is given by a membership degree. The framework applied to develop the FL algorithm was based on the study from Jazizadeh et al [14]. This approach was grounded on the Wang-Mendel method to create fuzzy logic descriptive models [20].

3.2.4 Predicted Mean Vote (PMV)

The PMV-based method considered that a PMV index below -0.5 corresponds to a preference towards "Warmer", above 0.5 is associated with a preference to the class "Colder" and values between -0.5 and 0.5 indicate a preference of "No change". The implementation of the PMV model was performed by applying in Matlab the algorithm defined in ASHRAE 55 [21]. Three input parameters to determine the PMV index were varied in the method to establish the best performing configuration in terms of classification performance. The clothing level was varied between 0.5-1.2 [clo] accounting for typical garments for summer and winter respectively; the metabolic activity rate between 1-2.1 [met] was tested, corresponding to a range of physical activities that can be performed in offices, from being seated, relaxed to walking; and the mean air velocity was varied between 0-0.12 [m/s] representing the maximum range allowed in landscaped offices, according to ISO 7730 [22].

3.3 Performance evaluation

Identification of the category or class a new data point belongs corresponds to a classification problem. The algorithms tested in this assessment were evaluated by their capacity to classify thermal preference categories based on thermal environment measurements. How good a classification algorithm (or classifier) performed depended on the number of correct and incorrect guesses. When a data point was correctly allocated in a certain category "A", it was called true positive. Similarly, the data that was correctly not allocated in that category was called true negative. On the other hand, the data that was incorrectly classified as "A" was called false positive. Finally, false negatives were data that was supposed to be "A" but was classified in another category. The True Positive Rate (TPR), also named hit rate or recall, is defined as the ratio between the number of true positives and the total number of positives. The False Positive Rate (FPR) or false alarm rate, corresponds to the ratio between the number of false positives and the total number of negatives. TPR states the proportion of positives correctly classified, whereas the FPR gives the probability of wrongly allocating a category as negative. From TPR and FPR, the Receiver Operating Characteristics (ROC) was obtained [23]. The ROC is a two-dimensional plot, where FPR is placed on the x-axis and the TPR on the y-axis, as shown in **Figure 2**. This graph represents the trade-off between benefits (true positives) and costs (false positives).

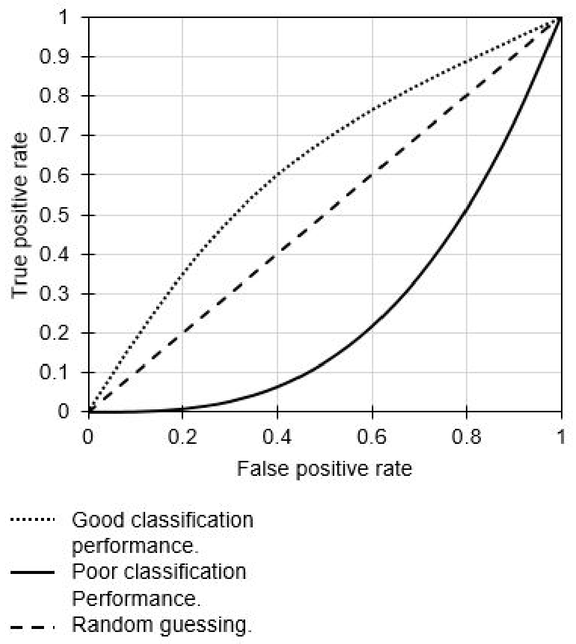

Figure 2. ROC curve example.

The analysis of the classification performance in the framework presented in this report is based on the Area Under the Curve (*AUC*), which is a scalar number that simply represents the area under the ROC curve. The *AUC* is equivalent to the probability that a classifier will rank a randomly selected positive event higher than a negative selected one, i.e., the probability that a class will be correctly classified as such [23]. It can take values between 0 and 1, corresponding to the minimum and maximum a classifier can perform. An *AUC*=0.5 means that the classifier predicts as many positive instances as negative ones, which is called random guessing. Accordingly, values above 0.5 are generated by well performing classifiers and below 0.5 for poorly performing ones. As the aim of the algorithms evaluated in this report was to guess three different thermal preference categories, a multi-class *AUC* was taken into account. This approach calculates the average *AUC* of all classes, considering a method called "each class against the rest", represented in Eq. 1 [24]. This method assumes that all classes have uniform distribution, calculating the probability of classifying correctly a class against the others, which is then averaged with the probability from the rest of the classes.

$$AUC_{mc} = \frac{\sum_{j=1}^{c} AUC(j, rest_j)}{c} \quad (1)$$

Where AUC_{mc} is the multi-class area under the curve, c is the total number of classes, j is a class and $rest_j$ represents all the classes different from class j.

4 Results and discussion

During the survey period, occupants were not forced to participate nor to provide a specific number of votes to avoid influencing their everyday activities. Thereupon, the number of votes per participant along the surveyed period varied considerably (**Figure 3**). In spite of the daily reminders and the simplicity of the survey, a decreasing trend in the number of daily votes provided was observed.

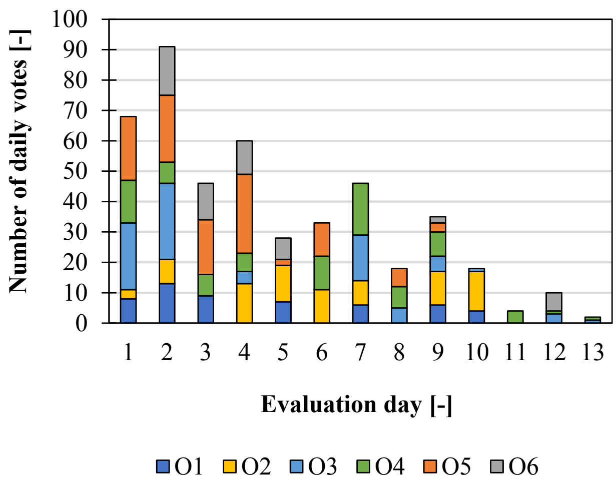

Figure 3. Number of daily thermal preference votes provided by each occupant along the evaluation period.

Table 1 illustrates the statistical characteristics of the *TPV* resulting from the assessment. The table shows a lack of variability in the votes, considering that occupants could vote within the *TPV* range between 0 and 18. A narrower range of *TPV* was obtained because of the reduced variation in the air temperatures (**Table 1**). The percentiles show that the votes were mainly biased towards low *TPV* associated to the category "Colder". This result suggests that the occupants were in general more affected by warmer temperatures in the room than the opposite. Thus, the data provided to the algorithms was not equally distributed among the

Table 1. Statistical parameters of the *TPV* per occupant obtained from the evaluation. O: Occupant, STD: Standard deviation.

O	Percentiles 5/10/90/95	STD	Mean	Median	Number of votes
1	3.0/4.4/11.0/11.0	2.5	7.8	8.0	55
2	8.0/9.0/12.0/12.0	1.9	9.7	9.0	80
3	5.0/7.0/10.0/10.0	1.7	8.6	9.0	82
4	7.2/9.0/12.0/13.0	2.0	9.8	9.0	84
5	4.0/5.0/13.0/14.0	3.1	9.4	9.0	110
6	4.7/6.0/14.0/14.3	3.1	10.3	11.0	55

three classes considered, a problem called imbalanced data. In addition, the percentiles reflect that the classes were not uniformly distributed, i.e., the probability of predicting a vote within a class was not constant. As described by [24], uniform distribution is a basic assumption to evaluate the classification performance of an algorithm by using the multi-class *AUC* described in Eq.1. In practice, it is difficult to have approximately the same number of *TPV* values in each class per occupant. Occupants would need to be exposed to different thermal environment conditions during equal periods of time when obtaining the training data. It is therefore a challenging task to characterize accurately the classification performance of a learning algorithm that aims to predict occupants' thermal preferences.

The percentiles and standard deviations in **Table 1** show that occupants 1, 5 and 6 provided votes with higher variability. The feedback from those three occupants were chosen as input data to test the learning algorithms and compare them with the PMV method. The reason was to ensure that all the thermal preference categories had sufficient data points, minimizing the effects of imbalanced data.

Figure 4 shows that all methods had a better performance than random guessing (*AUC*=0.5) thermal preference categories. Therefore, all classifiers will probably predict more positive instances than negative ones. This shows a good performance considering that only *Ta* and *RH* measurements were provided to the methods. The classification performance among the occupants was mainly affected by how many votes per occupant were provided, the distribution of the data points among the classes and the consistency of the votes from the occupants. Higher *AUC* values could be achieved if any of those factors were improved. The inclusion of data from additional parameters, such as radiant temperature and air velocity, could also improve the classification performance of the algorithms tested.

Overall, the methods with the highest performance were NB and PMV, accounting for a probability of correctly predict a class of 73% and 70%, respectively. The NB method assumed that *Ta* and *RH* were independent from each other. It calculated the mean and standard deviation of the training data, adjusting a PDF. Hence, it did not calculate individual factors related to each data point. That was the reason why it performed better than the other algorithms. By calculating variables that comprise a whole data set, it simplifies the learning process.

Figure 5 shows the performance of all methods with regards to each thermal preference category. Classifying incorrectly a category could yield to serious operational problems when applied in reality. Thermal comfort and health could be compromised when a HVAC control system regulates the thermal environment wrongly. For instance, controlling an indoor environment based on a preference towards colder temperatures instead of warmer, could have serious implications in occupants' well being. **Figure 5** shows that all methods except FL had a better performance when predicting the "No

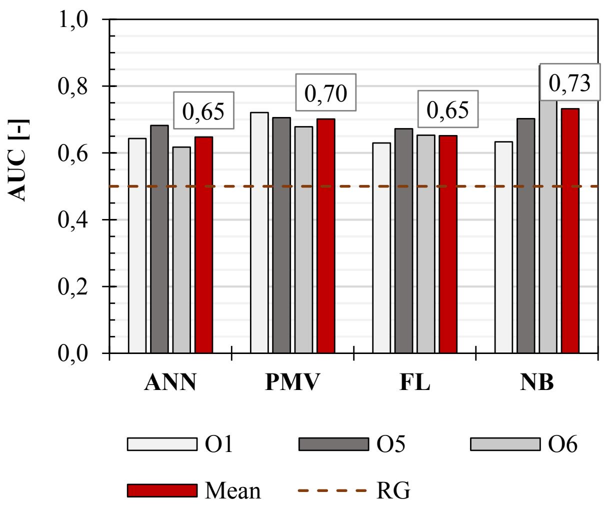

Figure 4. Classification performance represented by the AUC value for all four algorithms studied, taking into account the data obtained from occupants 1 (O1), 5(O5) and 6(O6). RG=Random Guessing line.

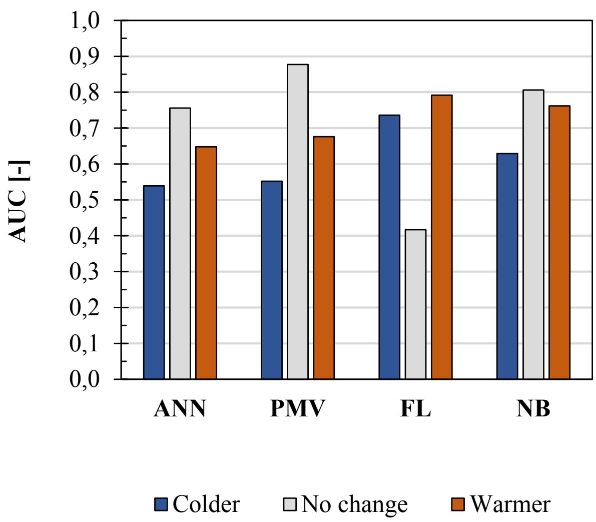

Figure 5. Classification performance represented by the AUC value for all four classifier studied, taking into account the three thermal preference classes predicted.

change" category than any other class. This is owed to the unbalanced data among the classes, presented in **Table 1**.

Some machine learning methods were more sensitive to imbalanced data than others were. They tended to favour the "no change" class for having the largest proportion of data, translated in a larger amount of true positives. In that context, the NB method exhibited less difference in the prediction of different classes. This method reduced the influence of biased data by assuming that all classes had the same PDF and by calculating parameters that enclose a whole data set. To avoid the problem of imbalanced data, it would be needed to expose people under uncomfortably warm/cold environments for a period equal to the period they feel comfortable. Since the last is unlikely to be applicable in reality, it is desired that the algorithm employed to predict thermal preferences overcomes the problem of not uniformly distributed classes. For that, it is proposed to make a sensitivity analysis of a classifier changing the distribution of the training data per class [25].

A correlation between the amount of training data needed by the learning algorithms and their corresponding classification performance is illustrated in **Figure 6**. This information allows the identification of how much the number of votes can be decreased with regards to the variation of the performance of a method. The data of all the occupants was combined and a linear correlation was applied for comparison purposes, even though the actual correlation may not be linear. A single data point corresponded to a thermal preference category with its corresponding measurement of *Ta* and *RH* (only *Ta* for the FL method). **Figure 6** illustrates that all the methods had a performance better than random guessing, even when the amount of training data was reduced to only 10 data points. The NB was not only the best performing method, but also required less data to generate a higher AUC compared to the other algorithms. The performance of NB and ANN increased with an increase of the amount of training data, whereas the FL method diminished its performance. Unlike the two other learning methods, FL does not rely on an iterative process to diminish the error during the training process of the algorithm.

When training the FL method, the first part of the training data read by the algorithm was used to construct the fuzzy sets. The rest of the training data did not contribute to create better fuzzy sets, as they were already created by the first data points read. Thus, providing more data point to the FL algorithm did not improve its performance.

5 Limitations

There are a number of limitations with regards to the framework proposed in this assessment. First, the evaluation period considered in the field assessment was limited. A longer period would allow having more input data for the learning algorithms, accounting for variations that the thermal preferences may have

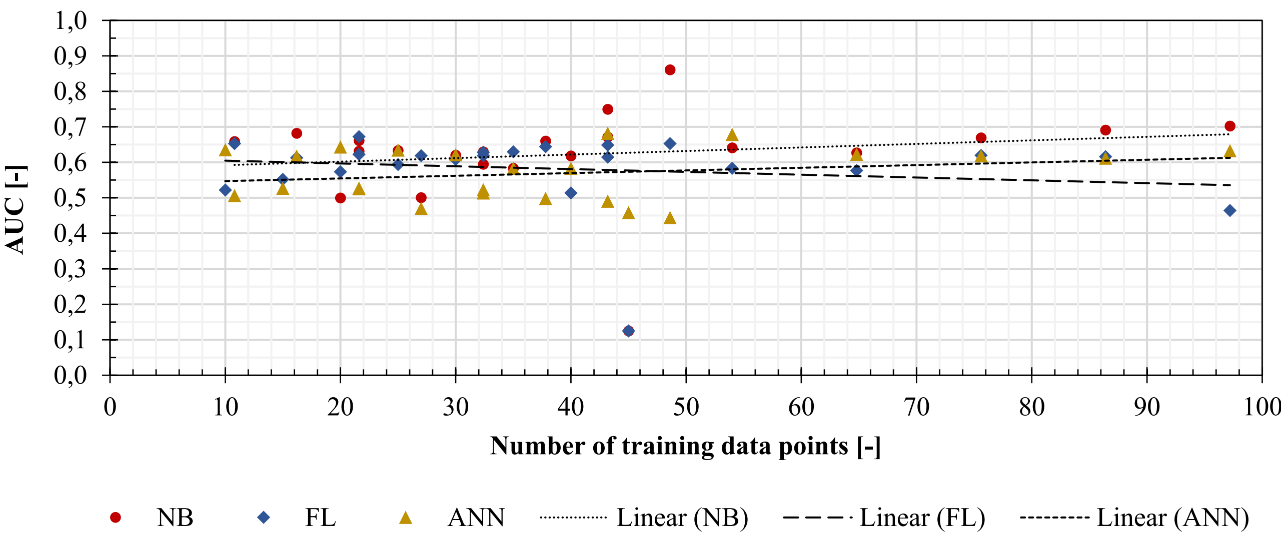

Figure 6. Classification performance represented by the AUC value as a function of the amount of data required for training on each of the three learning algorithms analysed.

with different weather conditions. As a result, the classification performance of the PCM-based algorithms could be analyzed with more training data. Second, miss-classification costs, i.e., the cost of not classifying correctly a category, were not taken into account. In reality, it does not have the same implications to classify a "Warmer" category as "No change" than classifying it as "Colder". This should be taken into account when characterizing the performance of PCM, especially when implemented in real applications. Third, it was considered that *TPV* was mainly influenced by air temperature and relative humidity. It would be needed to determine the required number of votes per occupant to minimize the influence of other factors that may influence the thermal preference votes. This will help to define the minimum number of votes per occupant needed to ensure a desired classification performance.

6 Conclusions

Personal Comfort Models (PCM) allow to focus on the thermal comfort needs of individuals based on local indoor environment measurements and feedback provided by them. Three PCM method and a PMV-based method were tested in this assessment. From the results obtained in this assessment, the conclusions were the following:

- When predicting personal thermal preferences, all the four algorithms tested (ANN, NB, FL and PMV) showed a better overall performance than guessing randomly, even though only air temperature and relative humidity were provided as input data.
- The difference between the performance of the PCM-based methods and the PMV-based method was very modest.
- The PMV method was capable of predicting thermal comfort at an individual level, with a probability of guessing correctly 70% of personal thermal preference votes.
- The NB method was not only the best performing method, predicting 73% of the thermal preferences, but also performed better at predicting each thermal preference category, requiring less training data than the other methods.

Future research efforts will be focused on the implementation of PCM in HVAC control loops, focusing on easy-to-obtain data. A field study for a long period will be considered in future assessments, accounting for the challenge of maintaining occupants' participation. ■

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Enhanced IEQ through Passive Earth Tubes in Canada

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The Canadian climate extreme lows (-20°C to -40°C) and moderate highs (+30 to +40°C) impact of building energy consumption in maintaining safe and healthy indoor environmental quality. Earth Tubes have been tested as a passive method to viably reduce energy costs of tempering outside air as a key part of IEQ.

Keywords: Earth Tubes, IEQ, Ventilative cooling, Net-Zero Energy, Green retrofit, Health and wellbeing.

Abstract

This paper will present the context and application of earth tube systems for the provision of ventilative cooling and general make-up air in the heating, ventilation and air conditioning (HVAC) sector of the built environment; with a focus on case studies in Canada.

The first author has a background practising as a Chartered Engineer in both the UK and also in Canada and has been designing and optimising earth tube systems since 1998, with several case studies built in the UK and Canada on both domestic and commercial buildings of various uses. The first author is also undertaking a PhD, investigating the effectiveness of earth tube systems to temper outside air for supply to buildings located in British Columbia in Canada, where there is a in a Cordilleran climate with up to 40 degrees Celsius (°C) and cold snowy winters down to −30°C. This paper will focus on a built case study example that has been investigated as part of the first author's PhD research in Canada. A discussion on methodology, drawn from the results of his case studies, to understand the safety and risks to health that need to be considered when using an earth tube system, especially to prevent mould growth and contamination in the pipe installation, is discussed. As is the different design approaches to earth tube systems for different building types, climate zones, occupancy loads and systems design are considered and evaluated.

The paper presents empirical monitored data from a case study that shows monthly temperature and energy

performance of the earth tube system, over a period of one year for 2014. These results demonstrate how building code compliance (energy and ventilation) can be met or exceeded by the application of earth tube systems in the supply of ventilative cooling to buildings in the Canadian climate zone (Cordilleran). The extreme swings in seasonal air temperature impact upon earth tube system performance with inter-seasonal characteristics. The results presented and discussed are drawn from ground temperature sensors installed from ground level downwards to the underside of the earth tube level, in the case study building presented. The main conclusions drawn from this research show that before starting with an earth tube system design there are fundamental considerations which should be addressed. These include climate zone, soil conditions, air flow, building occupancy patterns, HVAC system and Building Management System (BMS).

The studies show that once the above considerations have been addressed, then the potential for earth tube systems as part of a ventilative cooling strategy will be capable of meeting core demand for occupant comfort, without relying on conventional oil and gas fuelled HVAC systems. Thus, significantly reducing carbon emissions for cooling and space heating and energy costs.

Introduction

This paper focuses on earth tube systems in the cold climate of the Canadian climate zone (Cordilleran), with up to 40 degrees Celsius (°C) and cold snowy winters down to -30°C. The monitored data from a case study building will be presented to demonstrate the ventilative cooling potential of an earth tube system in this climate. Furthermore, the potential for earth tubes to provide pre-heat in winter will also be explored and supported by monitored data from the case study building.

The case study and monitoring methodology is discussed for a residential building in the interior climate zone of British Columbia, Canada. The existing 105 metre squared (m²) house is 60 years old in 2018, but recently underwent a refurbishment and extension to add an extra 35 m². The design of the earth tube system (ETS) is also discussed, which is 48 m² or 34% of the total building area. The results of the 12-month monitoring are also discussed.

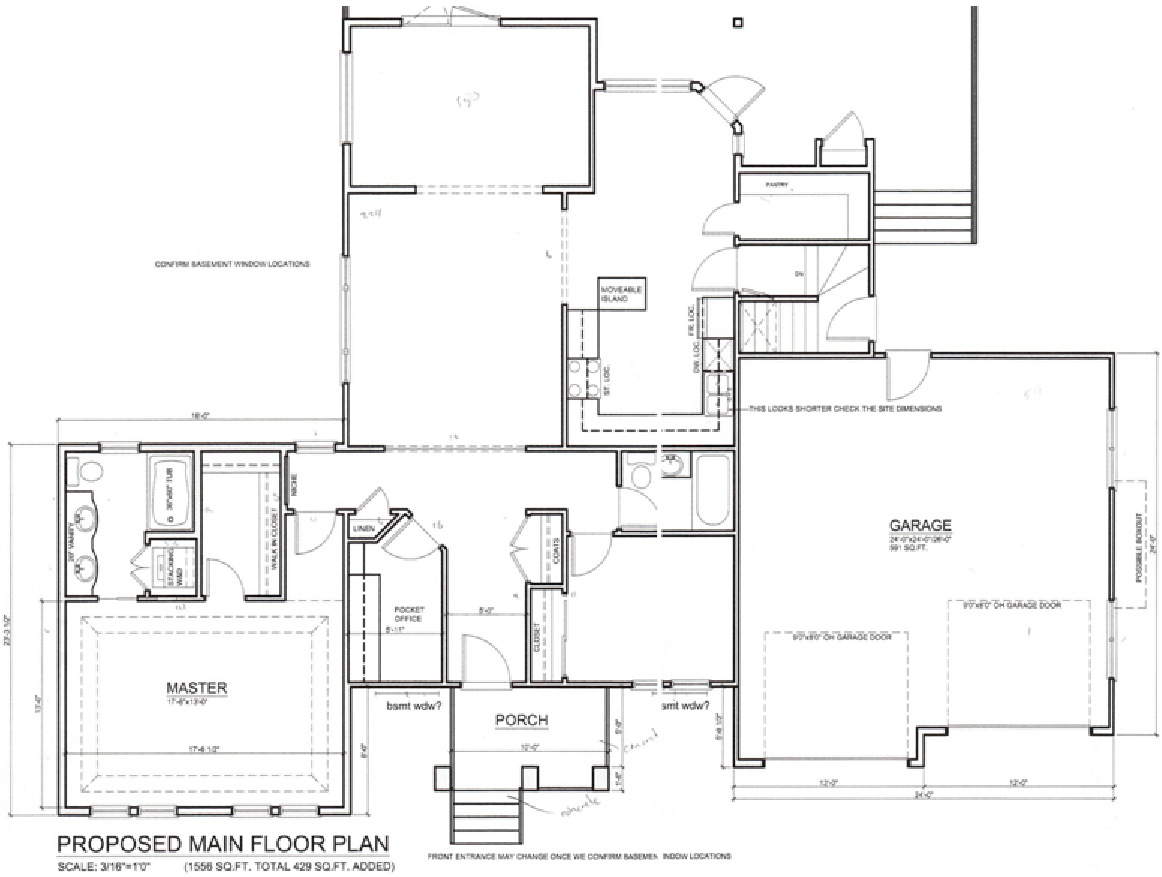

Figure 1. Architectural plans of the case study house.

Methodology for the Earth Tube System

The type of ETS that is documented in this paper is a single pass supply of outdoor air, primarily to provide cooling to the master bedroom and main living areas of the case study house, see **Figure 1**.

The pipework configuration comprises four pipes, each 100-millimetre (mm) diameter (Ø) running in parallel at an average of 50mm spacing in a common trench. There are two 90-degree bends in the pipe runs with each pipe delivering 18 litres per second (l/s) at an average air velocity of 2.2 metres per second (m/s). The ventilation system is a single in-line fan with direct ducting to supply tempered outdoor air directly to the master bedroom and living areas, see **Figure 1**.

The exposure of the outdoor air inlet is deliberately located on the north side of house, mostly in the shade, to allow the air to be drawn from a space with a cooler microclimate of a quiet suburban garden.

Material of the earth tubes

The earth tube material is High Density Polyethylene (HDPE) and constructed with a solid and corrugated profile. Each pipe is approximately 23 metres (m) in length in continuous monolithic sections, with no joints to reduce risks of leakage and contamination to the air stream (see **Figure 2**).

Installation of the earth tubes

The earth tubes are bedded in a trench surrounded by soft sand to protect them, with a soil depth cover (from crown to surface) of 1.6 metres (**Figure 3**). The earth tubes run adjacent and parallel to the insulated basement foundation wall. The local soil conditions are a mix of loamy sand and clay, the site is well drained being located on a gently sloping hillside, facing south-south-east in a suburban low-density neighbourhood.

The site conditions above the earth tube is exposed and open to atmospheric and climate conditions, with a surface treatment of a mixture of lawn and concrete paving, as well as a herbal garden, to assist with air quality improvements (see **Figure 4**).

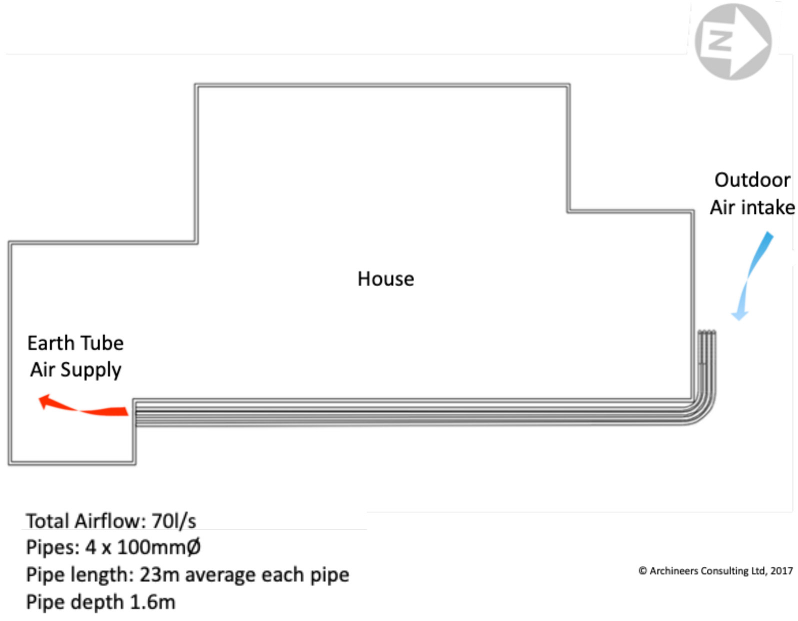

Figure 2. Plan view of earth tube system at case study project.

Figure 3. Trenching and laying earth tubes for case study project.

Figure 4. Outdoor air inlet box and filter housing (circled) – case study house.

The solar exposure above the earth tubes is partially shaded by the house, and a substantial Douglas Fir tree in the front garden, although in the summer months, there will be a degree of direct sunshine in the early morning from sunrise until 08.00 am.

The outdoor air inlet to the earth tubes incorporates filtration of fine insect mesh and a regular 25mm thick filter screen – as commonly used in residential scale air-handling systems and furnaces, see **Figure 5**.

Monitoring of earth tubes

The monitored data for the case study has been recorded using wireless sensors linked to gateway, with continual pulsed recording every 30 seconds. The sensors are manufactured by Omni sense, and comprise a series of wireless sensors and a wireless gateway that is hardwired into the internet modem, see **Figure 6**.

The wireless sensors are located inside the outdoor air inlet box and inside the ductwork header upstream of the supply fan (see **Figure** 7).

The wireless sensors record two points of data, outdoor Air Temperature in degrees Celsius (OAT) and Earth Tube Air Temperature in degrees Celsius (ETAT). The difference between these two temperatures is of interest in determining the delta Temperature (ΔT) and ultimately the efficiency of the ETS.

Figure 5. Air inlet with screen, mesh and filter – all upstream of the earth tubes.

Figure 6. Omnisense, S-900-1, Wireless T, %RH, WME Sensor.

Earth Tube System description

The ETS supplies tempered outdoor air to a single-family house primarily for the purposes of summertime cooling and wintertime indoor air quality. The ETS meets 100% of the cooling needs of the master bedroom and living spaces within the house, and the volume of cooled air supplied to the spaces is controlled by a variable speed inline fan. The ETS provides tempered outdoor air to the living spaces through the year to improve indoor air quality. The benefits are most notable in the winter when the indoor air quality (IAQ) is enhanced through the supply of tempered outdoor air that is pre-warmed such that there are no cold draughts. Top-up heat is provided to the living spaces through perimeter heating to offset both the envelope losses and the ventilation air that is mixed with room air.

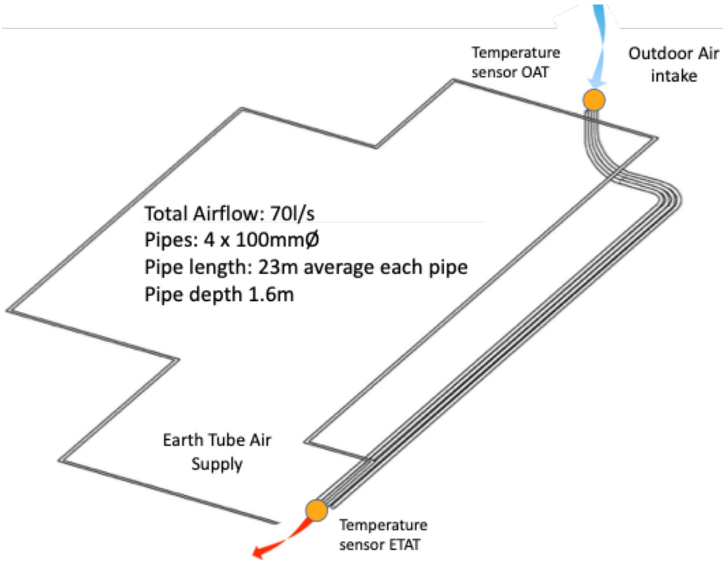

Figure 7. Isometric of ETS with Temperature Sensors shown.

Figure 8. Ductwork header connected to earth tubes and fan unit.

Cooling options from the earth tube system

As an alternative to the earth tubes for cooling, the owners would most likely have opted for a window air conditioner as their first choice of system. The house has no forced air ductwork (common for heating and cooling in Canada) so a central forced air-cooling system would not have been a viable option for the case study house owners. Another alternative would have been a ductless mini-split system. But the mini-split system does not have the benefit of outdoor air supply, so this is not quite an "equal/approved" system as the earth tube has added benefit of tempered outdoor air exchange. The earth tubes provide tempered outdoor air (all year) and meet the cooling needs in the when the climatic conditions require (typically June to September). Therefore, the most viable alternative would have been the window A/C units.

Controls of the earth tube system

The ETS supplies tempered outdoor air by an inline fan. The fan is manually operated to control volume of air flow supplied. Depending upon the time of year the homeowner will require different volumes of tempered outdoor air to be supplied to their living spaces. The manual operation is deliberate in the manner that it requires a hands-on approach – so that the operator can manage their comfort simply to meet their needs – something very a different o typical HVAC that is electronically controlled. Detailed operational procedures by the owner are not fully recorded. However, through discussions with the owner, there are two main modes of operation that have been established: (i) in summertime, the fan operates based on temperature demand for cooling; (ii) in winter the fan is operated based on indoor air quality needs.

For the purposes of the analysis, an average period of ten hours per day has been applied during the most occupied period of the day, from 08:00 to 18:00. This allows the efficiency to be compared to a traditional system for heating or cooling the equivalent volumes of air from the outdoor temperature to the delivered temperature. The baseline delivered air temperature has been set based on degree days of 18°C dry bulb (DB). Therefore, the energy saved by the ETS compared to business as usual is based on the temperature difference between tempered earth tube air and direct outdoor air to a temperature of 18°C DB.

Monitored data

The monitored data is shown in **Figures 9-12**.

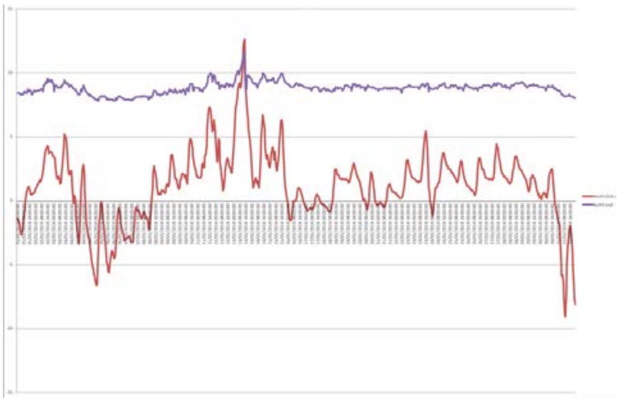

Figure 9. OAT and ETAT for case study house – January.

Figure 10. OAT and ETAT for case study house – April.

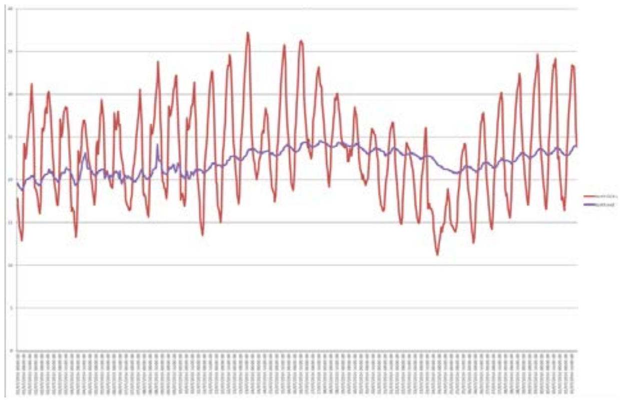

Figure 11. OAT and ETAT for case study house – July.

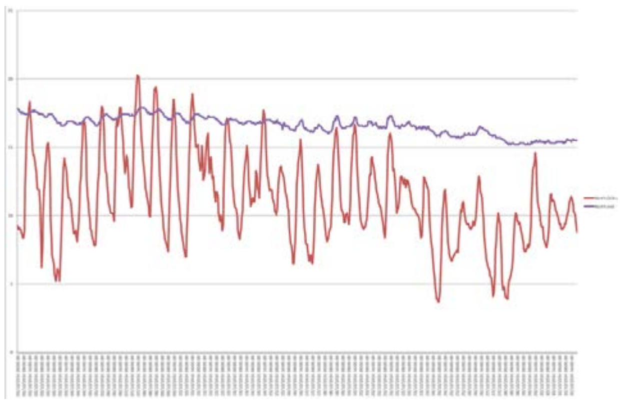

Figure 12. OAT and ETAT for case study house – October.

Results analysis

The monitored data is recorded with temperature and relative humidity reading taken every ten minutes over a twelve-month period.

The analysis uses average daily outdoor air temperature (OAT) and earth tube air temperature (ETAT) per Month based on daily averages 10-hour days (8am–6pm).

Degree Days are used as a reference to compare the earth tube performance with business as usual. Degree-days for a given day represent the number of degrees Celsius that the mean temperature is above or below a given base. For example, heating degree-days are the number of degrees below 18 °C. If the temperature is equal to or greater than 18, then the number of heating degrees will be zero. Normals represent the average accumulation for a given month or year. Values above or below the base of 18 °C are used primarily to estimate the heating and cooling requirements of buildings and fuel consumption.

The baseline conventional scenario with no earth tube array was established using the building HVAC system to temper the outdoor air to meet the 18°C degree day standard assessment. The calculation for this is as follows:

$$Q = C_p \cdot m \cdot (T_{18} - T_{OAT})$$

where:
Q = heat load in kilowatts (kW);
C_p = specific heat capacity of air in kilojoules per kilograms per degree Celsius – assumed as constant 1.2 kJ/kg/°C;
m = mass flow rate in litres per second (l/s);
T_{18} = 18°C as per degree day assessment;
T_{OAT} = temperature of outside air;

- The annual energy savings in cooling mode are: 30%
- The annual energy saving in heating mode are: 46%

Post Completion Review

The owners of the house have experienced an enhanced internal environmental quality since the completion of their project. This is likely due to several factors, including improved envelope, modernized kitchen and living spaces, as well as the provision of better air quality and cooling from the earth tubes. Following a recent inquiry to the owners, we were informed that they are very happy with the system and also happy to share the monitoring for the furtherment of understanding and application of earth tubes in the Canadian market.

Discussion section

The primary driver that led the author into this field of research was related to the health of and well-being building occupants. Health is important – started at the main driver as similar findings (Clements-Coombe, 2008) who found that indoor air quality is poor – especially at times when outdoor air temperature is not suitable for a natural ventilated operation. The results show that an additional 46% outdoor air can be supplied to the house in winter with zero energy penalty. This is an important factor as it could encourage the homeowner to operate the earth tubes more frequently in winter to improve IAQ.

The summertime cooling (June-Sept) benefits go beyond outdoor air volumes and identify that the internal conditions of the house are maintained through the very hot summer (July peaked at 37.5°C). The earth tubes were sized for outdoor air tempering but ended up being primarily used for summertime cooling.

The design of the system has several factors that need to be accounted for, including:

- Climate zone – including seasonal extremes in addition to annual averages/medians of temperature
- Sub-surface conditions – including soil type and soil temperature, ground water, depths of bury
- Air flow requirements – for ventilation air to manage IAQ.
- Air flow requirements – for meeting thermal loads, predominantly cooling but also tempered make-up air in the heating season
- Building occupancy patterns – related to seasonal, monthly and daily use
- Operational HVAC system – optimising effective interface; and
- Building Management System & controls including sequence of operation

Conclusions

The earth tubes are a simple technology – "well known", but not necessarily 'known well'. Despite the building energy codes becoming more directive with regard to improving energy efficient through better envelope, there is a still the factors of climate change that result in a growing need to provide cooling to buildings.

The earth tubes are shown to be a proven technology to provide free cooling, but also the factors of improving IAQ in winter – as well as summer – are further benefits, with no operational costs.

The factors such as passive survivability – "A building's ability to maintain critical life-support conditions in the event of extended loss of power", (CBE Berkeley, 2008) are enhanced through less reliance on complex mechanical equipment. The earth tubes are a simple technology that can assist the passive operation. ■

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- My Family for allowing me time to pursue my studies

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Halton

Halton 50 years.

Interview with Tarja Takki-Halttunen and Mika Halttunen from Halton Group

INTERVIEWER: **ANITA DERJANECZ,** REHVA MANAGING DIRECTOR

Anita Derjanecz: Congratulations to Halton's 50th anniversary. How did the family company start, and how has it been evolving to what Halton is today?

Mika Halttunen: My father, Seppo Halttunen created the company with his partners in April 1969. Few years later my parents bought out the investors, Halton became a family company and has remained one till today. When my father started the company, Halton was specialized in manufacturing equipment for supermarkets, refrigeration products among others. My father was an entrepreneur with manufacturing background, looking for new product ideas to manufacture. One day, when building a new factory in his previous job, he saw air diffusers being brought to the site, imported from Germany and England. He figured that this may be a good product to manufacture in Finland. That's how our ventilation business started. During the past decades we split the company between me and my brother. My family kept Halton and my brother the supermarket refrigeration company under the name Pan-Oston. I became the sole owner of Halton and invited Tarja and Krista, our oldest daughter as co-owners. Since 1997, Halton has been exclusively specialised in indoor climate.

AD: How did a family business expand to a global company? How much manufacturing do you have still in Europe?

MH: My father started the first international operation in 1978, he opened a factory in Canada. In the 1980's, we launched sales companies outside Finland. Today we are present in 35 countries and will add two more this year, ending up the country count at 37 in 2019. The USA is our largest single market, while Europe is about half of the whole company. We have production in 9 countries, in Europe we manufacture in Finland, England, France and Germany. Last week we inaugurated our second factory in the USA, celebrating at the same time 30th anniversary of Halton USA. Later this year, we'll inaugurate our second factory in China. We have been in China since 2005 and we've been able to make money there, which is not always the case, as this is not an easy market. Our position in certain segments is pretty good in the region. Halton has been in Asia since the 1990's. We started our operations in Malaysia, which probably made it easier to go to China. Malaysia is one of the easiest and most attractive countries to start business in the region. Everybody speaks English and the country a is ethnically diverse with three major groups. We relied on our local colleagues to settle in new markets. Our Indian colleague developed business in India, a Chinese colleague started operations in China and trained local people. Malaysia was the centre of our growth in Asia.

AD: Tell us also about your background and your history at the company.

Tarja Takki-Haltunen: We are both HVAC engineers. Initially, I wanted to become a ship builder, because my father was a director in a shipyard in Finland. I wanted to design big ships. But in the early 1980's the shipbuilding industry declined, and my father told me this is not a good choice. I was already at the mechanical engineering department, and I gave my father the book about available courses, as I was not sure what to study if not shipbuilding. He looked at the courses and said, well, this H-V-A-C probably works for system designers. This is how I chose HVAC.

We studied under Olli Seppänen's supervision. At that time, Olli started teaching at the University of Technology in Helsinki as a very energetic professor with radically new ideas. He has changed everything in the education of the university. We were in his first class, kind of his Guinee pigs. And the experiment worked out very well, there were many successful people in our class who then pursued excellent professional careers. We were two women with twenty men in that first year.

MH: For me, studying HVAC engineering was never a question. We met with Tarja at the university and graduated in 1988. Then we got married and went together to the USA to start our business there. We stayed for 3 years. While expecting our first child, Krista, my father told us that he considers retiring. We agreed that I will take over the entire company as CEO. For this we had to return to Finland.

Simulated operations are carried out in Halton's full-scale operating room at Halton Oy in Kausala.

TTH: Mika became CEO at the age of 31, very young if I think of it now. But then, we were young and thought why not? Let's do this.

AD: What do you consider as key success factors of growing towards a global company? What are the unique values at Halton?

MH: In our mission statement we talk about enabling human well-being in demanding indoor environments. This is our reason of existence. We believe that everyone has the right to a healthy indoor climate.

A key to success was that we aimed at finding niche areas from the beginning. Already my father understood that HVAC is a big industry with major players from the US, Japan, nowadays from China. Competing with them would be a mistake. Instead, we seek niche areas that are difficult enough for smaller companies to compete, and small enough that big companies are not interested in playing there. We have been following this strategy from the start. We strongly believe in being specialist in specific segments. Finland is a too small market for niche areas, but if the market is global, there are no limits for growth. Excellence is another core value at Halton. Our main goal is to become the experts to the experts. Meaning that in these niche areas we want to be so good that we can provide value to the best expert in the world in the field, so they ask questions from us.

TTH: Customer-centricity is also our core value. A good example is the health segment, where we sell directly to the end-users. We built in our innovation hub in Kausala a real-scale, fully functioning operation room. We invite surgeons and nurses to visit the operation theatre where we perform simulated operations while measuring indoor air quality. We test new clothing for doctors and demonstrate how their occupational well-being evolves during an operation. We simulate the same circumstances like during an operation, only without the patient. If you talk to end users, your key customers, you can understand their real needs. Right now, health is probably one of our most important growth engines. The segment grew 70 % in 2018, it will grow 50% this year and the potential is huge. From here, we can expand to the pharmaceutical industry and other related fields. In Europe, most hospitals were built in the 1960's and we expect a massive wave of hospital construction and renovation in the coming years.

AD: What are the important challenges, market trends and opportunities on the way towards a sustainable future with healthy indoor environments?

TTH: Indoor climate and wellbeing is a much more rounded subject than other fields. There are still many problems people face regarding indoor climate, which we couldn't solve. Just recently a Finnish paper brought a controversial article about mould in buildings. Some doctors claim that mould is not the real problem for health, as everybody exposed to it develops antibodies in their immune systems, while only few of them develop symptoms of respiratory diseases. I think that the article was quite controversial, as it diminishes the users' experience. Occupant satisfaction and wellbeing should be much more appreciated. We shall measure indoor climate performance based on the satisfaction and feedback of the people using the building. Engineers like to measure everything with numerical indicators and complicated formulas. But at the end of the day what matters is how people perceive the indoor environmental quality.

MH: And we must respect individual differences and provide individual indoor climate. Technology should find better ways to make sure that each person has a possibility to affect indoor environment. This is the trend and the direction where we must go.

TTH: At a certain point of my career, I left Halton to start a company called Indoorium. Our mission was to save people in office buildings from deteriorated indoor environmental quality. We localized the UC Berkeley occupant satisfaction survey first time for Finland, which became a mainstream IEQ assessment tool. Those years I learned that if more than 30% of the occupants complain about IEQ, there is always a technical problem. And as the end-users were able to indicate the locations of their workplaces it was easy to see that the complaints accumulated to certain floors and zones. It became also obvious that our sector doesn't care about its customers as much as other industries. If in the car industry 30% of customers wouldn't be satisfied with a product, you could not sell that car. But in buildings this is not a big deal. Unfortunately, this doesn't seem to have changed much in the past 20 years.

MH: In general, I see the market trends in our industry optimistic. There are many drivers that create opportunities for us, I see the future of our industry very positive. We focus on well-being. What can be a more noble way to run a business than providing health and well-being.

TTH: Climate change is the biggest challenge we face. We must prevent and mitigate it. At the same time, we must improve indoor climate in buildings, while the outdoor environmental conditions are getting worse. This is the key challenge we must deal with. Energy efficiency can have only limited impact. It may happen that we save energy but deteriorate indoor environmental quality. And this, of course, we should never do, because buildings are for people. If we can solve the dilemma of producing CO_2 free energy, then we can use the necessary amount of sustainable energy to create better indoor climate.

Halton received a special REHVA award at the REHVA AM2019 Gala Dinner in Bucharest commemorating their 50th anniversary and to thank the company for their longstanding support.

AD: Healthy buildings and comfort gained more attention among EU policy makers and in the revised EPBD. Digitalisation and building automation even more. Can ICT provide better solutions for individual demand control?

MH: The starting point must always be the building user who we serve. The definition of user-centred performance criteria is of key importance. ICT and new technology may help, for instance we can now measure, monitor and predict how systems operate. However, first we must ensure that the basic components function as they should. Even in Finland, where we believe that we know what we are doing, HVAC systems do not work properly. Yesterday, we had an interesting discussion about demand-based ventilation with Dr. Risto Kosonen, our former colleague, now a professor at Aalto University. He found that in 8 of 9 buildings, demand-based ventilation was not functioning properly. And now they talk about digitalisation and AI. But the basic systems still do not operate as they should. And the systems can become too complicated.

TTH: I agree. We must never start from the technology, but from the customers' need. Things will become more complicated if you add more technology. Nowadays, for example, people start valuing more natural ventilation. I don't know if this is a threat, it can certainly be a health hazard in urban environments, and we must be careful. If systems get more and more complicated and the image of our industry is that these complex systems never work, than customers will naturally favour simpler technologies.

AD: You provide solutions in demanding environments like health, professional kitchens or marine industry. Tell us about a latest innovative product solution and how you developed it.

TTH: From 2013, we started to develop strategically the health segment, I oversaw the process for 5 years. We organised a business plan competition within Halton and the Board evaluated the plan on the health segment as the best. We chose 4 specific spaces to focus on, allocated resources and organised the work differently than before. Dr. Kim Hagström, who has been working in the field for 10 years, was a key expert in the process. Skanska, a major customer was constructing the Karolinska hospital near Stockholm at the time, and we decided to develop an entirely new system with them. We had the necessary knowledge and technologies to serve this sector, still it was a big effort to build a whole new business segment. It took 2 years to come out with new products. Today, we offer turn-key operating rooms with specialised ventilation solutions for ultraclean operating environments called Halton Vita solutions.

We realised that our customers prefer the end-result delivered instead of dividing the process in components. This was a learning curve for us. From a component provider we became an integrator who coordinates all contractors in the process. This is a paradigm shift, we are not a supplier like other companies in this industry, but we sell the hospital owner 50 operating rooms as a turn-key delivery. And this way you can guarantee the quality of the end-result. The next phase may be that we will sell the operating room air as a life-cycle service, which may change the whole industry. I believe, it is possible to sell the clean air. And then you can guarantee the quality as a life cycle service, which will make lower quality companies disappear from the market. That's why we talk about the end-result so much. We want to measure it and sell it.

Halton is among the very first supporting companies of REHVA. What values do you see in the REHVA network? What can you suggest REHVA to serve better our industry?

MH: Of course, REHVA's mission is appealing for us. Coming from a small country, we strongly believe in international cooperation. Partnerships are natural with this background. Olli Seppänen has been very important in sharpening the focus and scope of REHVA, reaching towards a role like ASHRAE. In the US. The vision has been very good, being a leading organisation to foster

The Halton Vita OR Space solution for clean and ultraclean operating environments is based on the controlled dilution principle, which provides the required air cleanliness and recovery time for the whole operating space. In the controlled dilution principle HEPA-filtered air is introduced into the room in a carefully controlled manner, effectively displacing and diluting air impurities.

our industry in good ways. We had several excellent experts who were involved in the work of REHVA. We hope, that this direction continues, and this focus gets even sharper in the strategy. I've been in the Board of Directors of Eurovent Association for three years now. There, we also try to understand what's going on in Europe for the future. The American common market is so much simpler, and it is much easier for ASHRAE to take a leading role there. Of course, it depends also on money. It is very important that Eurovent and REHVA work together to make European industry stronger. Especially now, if we consider how the geopolitical situation is changing recently. We have lost the idea of free trade and markets. We go back to closed blocks both geopolitically and economically. The walls are going up again, we have China, Europe and USA as separate blocks. Coming from a small country, we are for free trade, and this is not the trend in the coming decade. Being part of the EU can help a lot in handling this situation. This is essential for us.

AD: Tarja, you are vice-Chair of Halton and with Krista, your daughter you are two women in the Board. How do you see the situation of women in STEM areas and in this male dominated industry?

TTH: Our daughter is also in the STEM field, but we have never pushed her towards it. I think, the most important thing is how fathers talk to their daughters about STEM areas, fathers can encourage their daughters to follow. At least in my case, my inspiration was my father. He was an engineer and I thought, this is cool. I want to do something like that. Men should notice the big potential in female engineers and women in tech and should promote women. In the company we should have plans on how to drive the company towards more diversity and inclusion. Not only in terms of gender, but all aspects, religion, ethnicity, sexual orientation, and so on. In diverse teams, the understanding of different possibilities is much better, and the quality of decisions improve on the long term.

Also, we should encourage women to take more executive positions. There is still this prejudice that women become experts, while men oversee the business. It shouldn't be that way. Women are sometimes very cautious if they want to take this path. We should encourage more women to take leadership roles, and then the situation can change. Hopefully, I have been a role model in this family company, but it can't be just one person. We don't have enough women in executive roles. The United Nations' "He for she" campaign is also relevant in the building industry. People in power choose who to promote and whose careers are enhanced. The people in power are still mostly men in our field.

AD: Mika, your band has played at the REHVA Awards Dinner and we had a very good party. Tell us about the Ärräpää Orchestra, and its long history of entertaining HVAC professionals.

MH: I've always loved music and started to play guitar at 11, in Kausala. In 1975, we started a band, because my older brother collected money for a school trip and organised a party and we were the cheapest band around. This was our first show. The name of the band has changed several times, and we were on and off during these years. After we made some records in the 1980's, everybody got occupied with their family and lives, we were occasionally playing for ourselves. Twenty years ago, Halton was celebrating 30 years' anniversary and our sales manager in Finland had the idea to organise a surprise performance at a customer party. We had three performances for

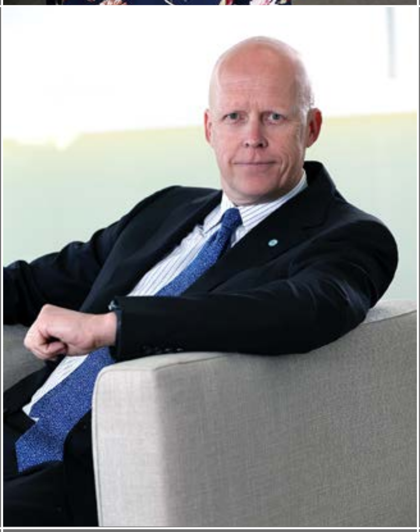
Ärräpää Orchestra playing at the REHVA Gala Dinner in Bucharest during the Annual Meeting 2019.

customers, and it was a blast. We wanted to continue and played in small clubs in Finland. We played at the Healthy buildings conference in 2000 invited by Olli Seppänen. Then the marketing teams of other countries heard about it and invited us. The next concert was in the USA in 2001 when the President of Halton USA organised a party for customers during an ASHRAE show. Romania is the 17th country where the band played.

Often, we organise with our local sales departments shows as side events in small clubs, like in 2008 after the Indoor Air Conference in Copenhagen. Last June we celebrated Halton Japan 20-years, we played in a beautiful club in Tokyo. They had a full recording gear installed, so we recorded the gig and released our album Made in Japan, which we distributed during the show at the REHVA Gala Dinner. If you did not receive a copy, you can find us on Spotify and YouTube. We enjoy a lot these shows. I keep telling our marketing people, when it is getting annoying, you must tell us, and we stop. Until now there are always new countries to play in. People take life too serious many times, especially in business. But you must have fun. Besides family, the most important part of our life is work. While spending so much time at work, why don't you have fun? Don't take everything so serious. ■

Tarja Takki-Halttunen

- Co-owner and Vice Chair of Board in Halton Group
- She has been serving Halton Group in many executive roles: Director of New Ventures Business Area, Director of Business Development Program, and Director of Logistics and Information Systems
- She founded Indoorium Oy and was HVAC Consultant at EKONO Oy
- She is Board and Executive Committee member in Technology Industries of Finland, Board member in the Confederation of Finnish Industries and in 3 technology start-up companies
- Born in 1962
- Former volleyball and flute player, likes golf, sailing, and knitting



Mika Halttunen

- Owner and Chairman of Board in Halton Group
- He took over the company form his father, Seppo in 1992 and became CEO and President of Halton Oy, then CEO of Halton Group
- He was conference President of CLIMA2007 - Wellbeing Indoors, in Helsinki
- He has held board positions in many HVAC related associations in Finland and is Vice-President of Eurovent Association
- Born in 1960
- Plays blues & rock in Ärräpää Orchestra and is Chairman of FC Lahti

- Tarja and Mika both graduated as engineers at the Helsinki University of Technology majoring in HVAC technologies under Professor Olli Seppänen's supervision
- After graduation they started together Halton's Indoor Climate business in the USA
- Tarja and Mika are married since 1988 and have 3 children

The Building as the Cornerstone of our Future Energy Infrastructure

Outcome of the DYNASTEE SYMPOSIUM in Bilbao, Spain, 10–11 April 2019

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Keywords: energy performance, energy infrastructure, building renovation, monitoring, analysis

The DYNASTEE network (www.dynastee.info) took the initiative to organise a symposium, following the 6th Expert meeting of IEA EBC Annex 71 at the University of the Basque Country in Bilbao. The aim of the symposium was to discuss the future role of the building stock in a changing society facing the climate challenges for companies, governments, researchers and most importantly, the citizen. Seven international renowned experts were invited to present their view on the energy transition and the development of an energy infrastructure integrating information and communication technologies and renewable energies in the building stock. In this context the speakers were asked to address the importance of dynamic and real data for reliable assessment. Two IEA EBC Annexes were invited to present the status of their research project. The selected topics for this symposium are related to monitoring, data analysis and modelling, energy standards, the gap between design and real values of energy performance of buildings, renovation of the huge building stock and integration of renewable energy resources. Interesting questions were raised by the audience and discussed by the experts. Will a carbon free society be feasible using innovative technologies? Will the greenhouse gas emissions and final energy consumption be reduced while maintaining the standards of living and working? Are citizens aware and willing to pay? Will it be feasible to adjust the present building stock to the requirements set by the political targets of reducing GHG emissions? Are the variable energy resources like wind and solar power giving the security of energy supply?

In the transition towards a new energy system, based on minimal carbon use and circular economy principles, the building is the cornerstone of the future energy infrastructure. Energy use in European buildings is still around 40% of the total final energy use. Decarbonisation of power and heat are high on the agenda of EU Member States. Present initiatives by governments for a proper energy transition are based on reducing energy consumption, increased use of renewable energy resources and making the energy infrastructure more intelligent measured with the Smart Readiness Indicator, (SRI) as mentioned in the Energy Performance of Buildings Directive (EPBD). Presently, the major part of final energy in buildings is heat. Soon, these needs will be converted more from (renewable) electricity. The energy transition should be a play between governments, industry and end-users.

Often not considered, the citizen should become at the centre of the energy system; from passive consumers to engaged energy customers. For that purpose, digitisation is essential, enabling monitoring and control of optimised energy use for a comfortable living and working environment.

The energy infrastructure needs to address the balancing for energy at different levels (transmission system operator (TSO) and distribution system operator (DSO)). The energy markets play an important role in managing the flows of energy in multi-directions. However, the level of balancing between the building end-user and the climate is not often carefully considered. Also, the energy flow between buildings and the energy networks will become more and more multi-directional. Buildings will have to become flexible and produce energy: electricity that is partly delivered to the grid, and heat that is stored in the building or underground. The near future may see more self-consumption in buildings, including the electricity stored in electric cars. One may conclude that buildings in which presently 40% of final energy is consumed, will take a more prominent position in the energy infrastructure.

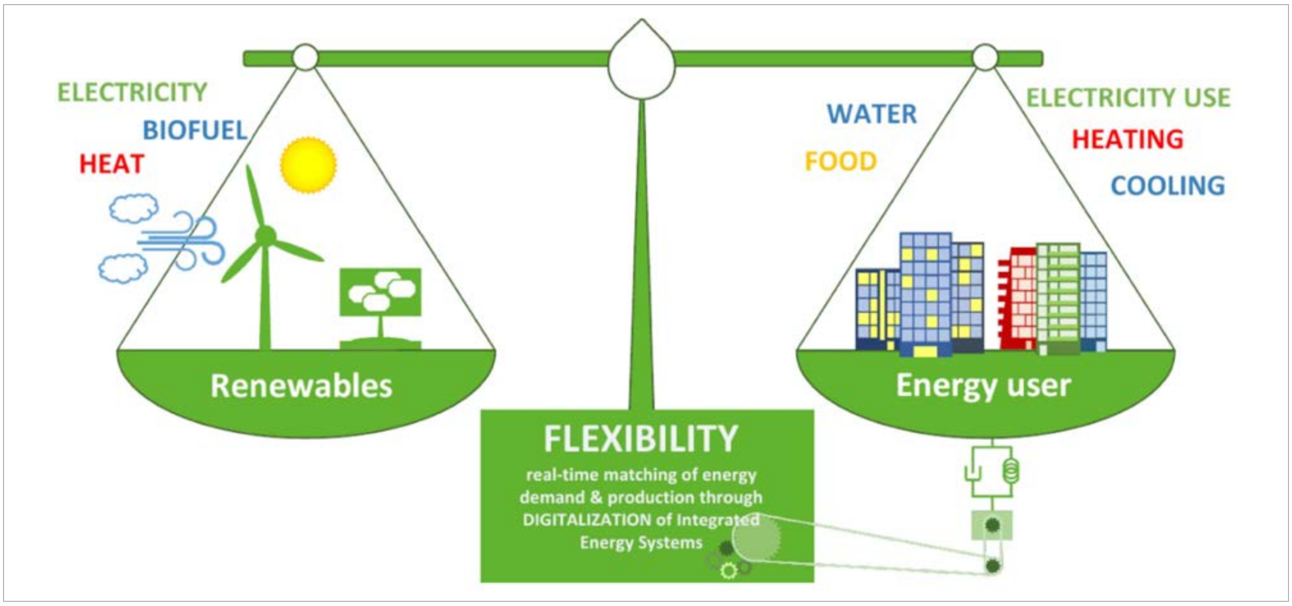
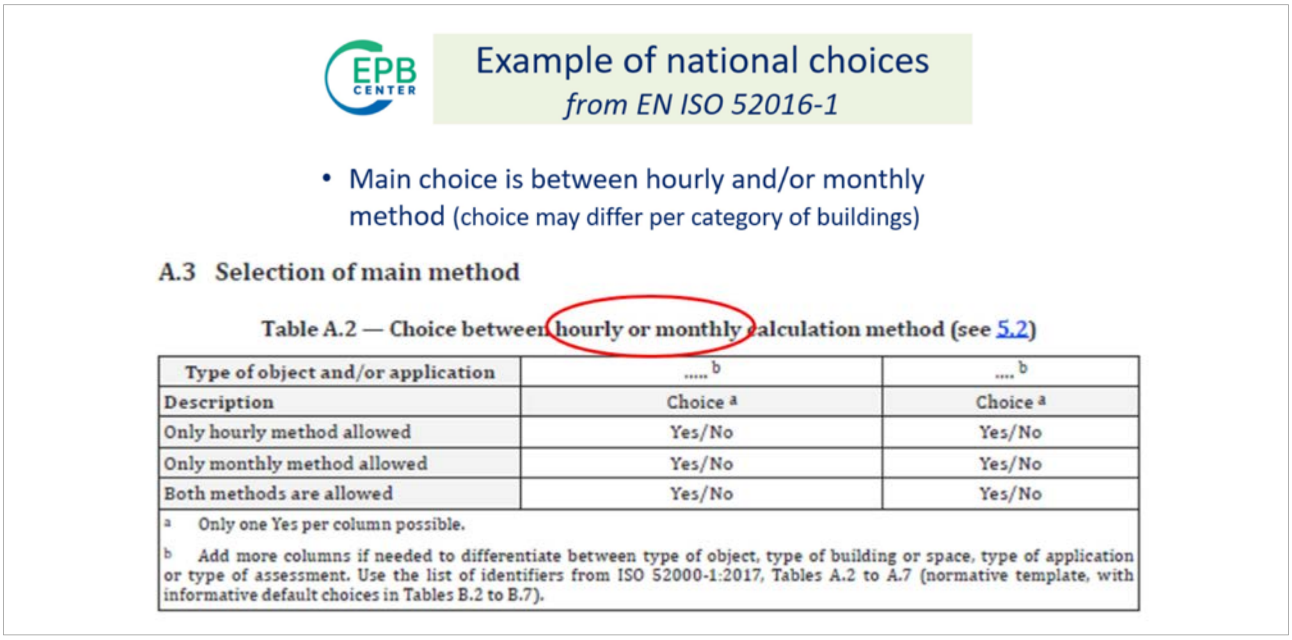


Figure 1. Source: DTU – Flexibility issue.



A.3 Selection of main method

Table A.2 — Choice between hourly or monthly calculation method (see 5.2)

Type of object and/or application	..... [b]	.... [b]
Description	Choice [a]	Choice [a]
Only hourly method allowed	Yes/No	Yes/No
Only monthly method allowed	Yes/No	Yes/No
Both methods are allowed	Yes/No	Yes/No

[a] Only one Yes per column possible.

[b] Add more columns if needed to differentiate between type of object, type of building or space, type of application or type of assessment. Use the list of identifiers from ISO 52000-1:2017, Tables A.2 to A.7 (normative template, with informative default choices in Tables B.2 to B.7).

Figure 2. Source: EPB Center – Example of national choices.

Summary of presentations and forum discussion

Energy standards and modelling techniques

Recently the EPB Directive 2010/31/EC, has been revised (2018) and related energy standards are updated (CEN/ISO). The use of EPB-standards for calculating energy performance, as well as for energy performance certification and the inspection of heating systems and boilers, ventilation and air-conditioning systems will be harmonised and have a positive impact for energy saving solutions. The EPB Center supports the implementation of these standards in national regulations. The modular structure of the set of EPB standards offers flexibility for specific applications at national and regional level by means of the national Annex. The assessment of the energy performance of a building, as required by the EPBD, is related to a single building (or building unit) and requires an energy performance certificate, expressed in primary energy. The EPBD links directly to standards for calculation as well as measurements when it concerns performance assessment. The EPBD addresses new, as well as renovated buildings. The EPB Directive mentions in article 2:

The 'energy performance of a building' means the **calculated** *or* **measured** *amount of energy needed to meet the energy demand associated with a typical use of the building, which includes, inter alia, energy used for heating, cooling, ventilation, hot water and lighting.*

Developments of a third, more **holistic** assessment approach are presented in several projects, based on administrative data and the application of reference buildings (which are measured on-site for that purpose). Whereas the EPBD deals with *individual* buildings, buildings have to be considered as part of urban areas or cities and will have a more important place when energy demand and production is concerned. The Energy Efficiency Directive (EED) addresses this issue also. Several international projects are studying the urban area in terms of infrastructure (roads, underground, water, etc.) as well as energy (production and load). Modelling software is developed in a very sophisticated way and uses modern techniques for planning and assessment. CityGML is regarded as a very powerful IT environment to develop the necessary software tools putting the building in the urban environment while taking advantage of innovative technological developments. As an example, the Sumstad project presented a dynamic model for heating and cooling demand at district level.

Figure 3. Source: CityGML – Building Level of Detail.

Figure 4. Source: CARTIF – CityFied project.

However, the major part of the energy standards are calculation techniques that are based on mathematical models and these are by definition, a simplification of reality. Validation of these models requires measured data and specific analysis techniques.

Renovation of buildings is key to meet the EU's energy efficiency targets. Recent revisions of the Energy Efficiency Directive and the Energy Performance of Buildings Directive address this issue. Much of the European building stock is in need of renovation (estimated about 50% of 210 million buildings) however, both relevant Directives define 'renovation' in an ambiguous way. The EED defines 'deep renovations' in a very broad way, as "renovations which lead to a refurbishment that reduces both the delivered and the final energy consumption of a building by a significant percentage compared with the pre-renovation levels leading to a very high energy performance". Renovation of the existing building stock requires a proper performance assessment in order to agree on feasible energy saving measures. The question remains always: why and when to renovate. To justify energetical and economic measures, practical and reliable methods have to be developed. Most of the measures are focussing on reduction of energy demand as well as optimising the efficiency of energy systems. However, as made clear during the presentation on the European CITyFiED project, the users – citizens – should always be involved in the decision-making process in order to understand and value the retrofitting actions and the RES integration, which is becoming more common. To this end, specific indicators are needed to justify renovation at district or urban level, which are clear, understandable to citizens, and useful to the performance evaluation.

Discussions are ongoing on the issue of the *gap* between designed and actual performance of buildings. Questions are put on the table in order to understand and reduce this *gap*. It may lead to the important question whether building simulation is ready to deal with present development in the building energy sector as well with recently reviewed standards.

Monitoring, metering and experimental measurements

To analyse and compare existing methods for the assessment of the energy performance of buildings, *dynamic measured data* from metering and in-situ measurements are required. The question if energy saving measures work in reality can only be answered when measurements are performed. The ENEDI research group of the University of the Basque Country carries out testing on building construction products and elements in laboratory as well as outdoors under real weather conditions in the LCCE laboratory. The University of Salford presented their test laboratory in which real buildings can be tested under controlled climate conditions. The new laboratory will open in 2021 and can test four homes, with and without occupants, in which modern appliances and innovative information technology can be applied to study the demand and supply of energy to the grid. In that context note that governments have emphasised that renewable electricity resources will have a prominent part in the energy transition, in the transport as well as the building sector. In practice this may result in movable and variable sources of electrical energy that may or may not be connected to the building by means of batteries (or other solutions). The Electric Vehicle (full electric, hybrid or other types) will take a more prominent position in our society for several reasons. Future buildings may therefore be equipped with electrical storage facilities and the new EH 2.0 laboratory in Salford will be equipped for testing these new conditions.

Figure 5. Source: LCCE laboratory, Basque Government. Outdoor testing.

Figure 6. Source: Salford University – EH2.0 Indoor testing.

The IEA EBC Annex 71 project presented the development of reliable methods for energy performance assessment based on in-situ measurements. Quantifying the actual performance of buildings can only be effectively realised by optimized in-situ measurements combined with dynamic data analysis techniques. Two approaches may be distinguished:

1) Co-Heating measurements on site (CEN TC89 WG13 is developing a standard) that requires specific conditions for testing in a limited period of time.

2) Metering data of electricity, gas, heat, water (regular readings with intervals ranging from a few minutes up to daily values). The roll-out of new intelligent metering equipment is at full speed in most EU countries. The advantage of metering data is that a growing amount of data is coming available and hence an improved accuracy is feasible. In order to split building related energy use from occupant energy consumption a combined statistical and dynamic method is investigated for the analysis of time series. *Validation* of the selected methods with measured data from field experiments or from metering readings (e.g. electricity, heat, gas and water) is required.

These collected data may be linked with different data sources (Internet of Things) and analysis tools to manage new domestic devices and building comfort in an energy efficient way. The Argonne National Laboratory presented the Waggle platform, an urban sensor project (Array of Things) providing environmental air quality data, to understand particular urban and environmental phenomena. The collected, huge amount of data in the cloud from a wide range of sensors, including image data, can be analyzed with advanced models and study urban mobility energy, building energy systems and building energy losses using thermal imaging and climate data.

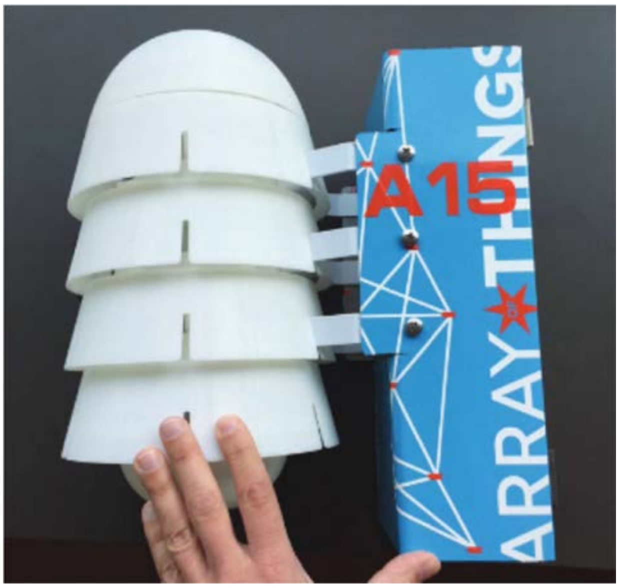


Figure 7. Source: ANL – Array of Things.

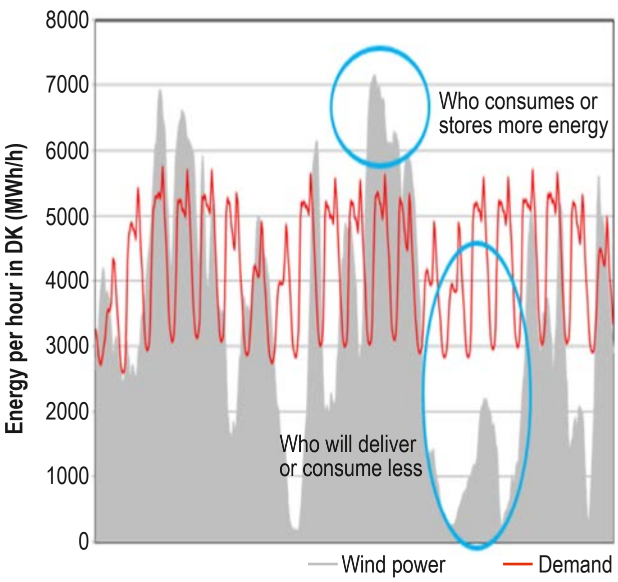


Figure 8. Source: DTI – Integration of wind energy; supply – demand.

Integration of renewable energy resources

Important to notice is the trend to move from one building performance assessment (EPBD) to district or urban levels (EED and RED) and hence the integration issue in the energy infrastructure. One of the highly interesting projects is the Danish CITIES project that covers the complex issues of applying Information Technology for the Integration of Energy Systems, in particular the variable renewable resources such as solar and wind electricity. The *Danish* government has set an ambitious target of weaning *Denmark* off *fossil fuels* by 2050. District Heat is a major component that contributes to the aim of reaching a fossil free society, through renewable energy. In addition, Denmark is one of the world's most digitalised countries. The CITIES project plays an important role in introducing the building flexibility (IEA EBC Annex 67). The Flexibility Index implies that it will be possible to design buildings, districts and cities such that they are optimized towards the local characteristics of the renewable energy resources. Results have been used on an international level to define the concepts of flexibility for smart energy systems.

Conclusions

In a final panel discussion with lively interaction with the audience, it was stressed that there is no conflict between energy efficiency and emission reductions, that flexibility and energy efficiency as a whole are more efficient on a larger urban scale, that energy poverty is an issue and energy solutions should be inclusive for all citizens. Pricing of energy and CO_2 is an important instrument. And the massive use of sensors should take account for the acceptance by the users and the own energy use. Finally, there should be a balance between investments in energy efficiency of the building and the energy system based on renewable resources.

The symposium discussed several aspects of the energy transition and challenges that may be faced. The need for real measurements to give evidence for justifying renovation, to make integration of renewable energies feasible and to manage the balance of energy demand and supply at the building and urban level. The very interesting presentations highlighted the innovations and strategies that the future energy infrastructure may see using the building stock as an essential part of the energy transition. ■

Speakers and Presentations of the DYNASTEE Symposium, 10-11 April 2019, Bilbao, Spain, please see www.dynastee.info for overview and download of all presentations.

DG ENER – DG JRC Workshop

'Development and Integration of Indoor Environment Quality Indicators in the EU Building Stock Observatory'

Report by **ANITA DERJANECZ**, Managing Director & **MATTEO URBANI**, Assistant Project Engineer

The European Commission's Joint Research Centre (JRC) was commissioned by DG Energy to develop a report on how IEQ indicators and data can be integrated into the EU Building Stock Observatory (BSO) in a user-friendly way. This task will lay the foundations to start building up a consolidated picture of IAQ, thermal comfort, ventilation, noise, lighting and building occupants' health based on a co-ordinated, systematic and centralised large-scale data collection of national/regional data for all Member States.

REHVA was involved in the definition and setup of the BSO working with BPIE and other partners in the frame of a DG Energy service tender. A consortium led by RICS (Royal Institute of Chartered Surveyors) took over the work in a second service tender to populate the database and improve the website and public interface. The team is facing the same challenge as the previous consortium: the unavailability of harmonised data across the EU Member States.

As a first knowledge sharing exercise, JRC and DG ENER organised a workshop on 13-14 June 2019 in Brussels. REHVA was invited as a stakeholder along with key academic experts in IAQ and IEQ issues in Europe. REHVA and many other participants were involved in a previous JRC study about tackling IEQ in the EPBD.

The objectives of the two-day workshop were:

- Reviewing existing IEQ indicators developed by EU MS and EU funded projects (with focus on IAQ, thermal comfort and ventilation criteria) which are used in connection with both, conventional and energy performing buildings.
- Devising a potential harmonized set of statistical indicators (distinguishing among IAQ, thermal comfort, ventilation) that could be generated for and used in connection with the EU BSO at different aggregation levels (local, national, EU) across various building typologies (e.g. public, residential, offices, school, etc.).
- Draft recommendations on feasible short and long-term strategies for retrieving data

The participants represented the European Commission services (DG ENER, DG GROW, DG ENVIRONMENT, DG JRC), European universities (Kauunas University – Latvia, DTU – Denmark, POLITO – Italy, University of Porto – Portugal), the National Institute for Health and Welfare – Finland, VITO – Belgium, German Environmental Agency – Germany, CSTB – France, IEA Annex 68 , Concerted Action EPBD members, relevant EU projects, HEAL (Health & Environment Alliance), INIVE and REHVA.

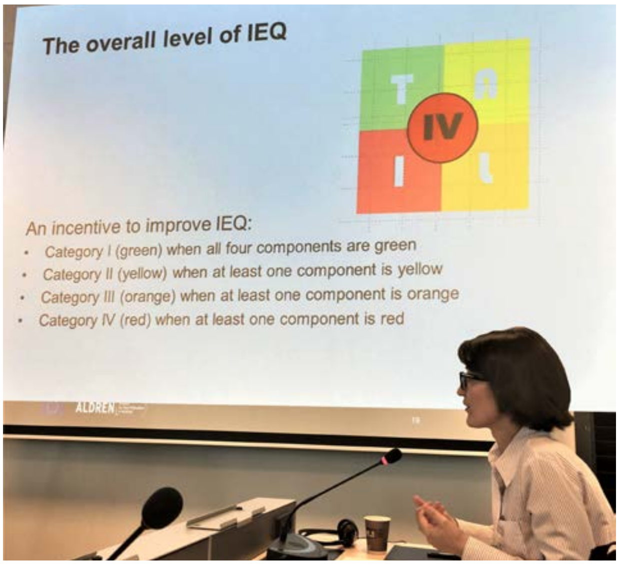
On the first day, the invited exerts presented different IAQ and IEQ assessment tool and indicators that are used in European projects and Member State level initiatives relying on EN standards and national regulation.

Corinne Mandin (CSTB) and **Pawel Wargocki** (DTU) presented the TAIL indicator developed by the ALDREN project, where REHVA is also involved partner. TAIL is proposed as a pragmatic, simplified indicator to assess the IEQ related impact of deep energy retrofit in non-residential buildings (offices and hotels) before and after renovation. The indicator considers the 4 components: thermal environment (T), acoustic environment (A), indoor air quality (I), luminous (visual) environment (L) according to the EN 16798–1 standard. The quality level is displayed using four colours, green representing highest quality and downgrading to orange, yellow and red for lowest quality. The overall level is indicated by I, II, III, IV following the standard. The participants gave useful inputs and comments to finalise the indicator.

Some issues raised in the discussions:

- How to define a pragmatic and affordable assessment methodology for the different building typologies
- Universal IEQ indexes should allow flexible application according to the different objectives of assessment.
- Some experts suggested considering also the variation of IEQ parameters over time, e.g. the variation during the different seasons. These can however lead to discrepancy in the BSO, as there are too many parameters and only very few data available to fee the database.

The second day of the workshop started with an introduction to the EC's information platform for Chemical Monitoring Data (IPCHEM). This platform gathers more than 300 million data combinations that are available to download for processing, visualizing the trend overtime and have an advanced view to identify and search multiple geographical areas on chemicals. Further development of the platform aims at evolving metadata to follow both chemical policies and energy performance of buildings. In terms of data collection, they follow an indoor air monitoring data integration plan (2018/2019) that will focus on a national monitoring program in Belgium, a survey of IAQ in insulated and not insulated school buildings in Tallinn, and on the developments of the EU funded project INSULAtE.



Corinne Mandin (CSTB) presenting the TAIL indicator developed by the ALDREN project

On the second day, the JRC organised a brainstorming among the expert panel to devise a potential harmonized set of IEQ indicators that could be generated for and used in the EU Building Stock Observatory at different aggregation levels and across various building typologies. Expert filled in two tables, the first one defined IEQ indicators in 3 dimensions: buildings assets, measurement & modelling, and occupant perception. The parameters identified for each dimension are summarised in table below.

Dimensions	Themes	Possible indicators/ Parameters
Building Assets	IAQ	Ventilation rate, ventilation type, filter type, outdoor air quality, air tightness, finishing materials, occupant density, internal source control, air polluting activities/occupant activities, type of insulation material, cleaning methods
	Thermal	Emissions heating and cooling systems, window surface, solar shading, risk of overheating, thermal mass, possibility to open windows, ventilation and temperature control, climatic conditions
	Visual	Window surface, daylight, direct sunlight, artificial light and control, solar shading, building surroundings
	Acoustics	Noise from surroundings, acoustics from the building (installation techniques and reverberation time), acoustic insulation, airborne noise (neighbours), and impact noise
Measurements	IAQ	Ventilation rate, CO_2, TVOC, PM2.5, benzene, formaldehyde, radon, asbestos, PCB, moulds, fibres, air tightness (blower door test), CO, NO_2, differential pressure, humidity
	Thermal	Humidity, radiant asymmetry, turbulence intensity, operative, mean radiant and air temperature, air velocity
	Visual	Daylight factors, illuminance, glare, uniformity of illuminance, colour temperature
	Acoustics	dB, reverberation time, sound insulation, intelligibility
Occupant perception	IAQ	Stuffiness, acceptability, eye irritation, visible moulds, odour annoyance, preferences about ventilation flow rate and window opening
	Thermal	Draught, thermal perception and preferences, activity and clothing-be compliant with the standard
	Visual	Perception and preferences about indoor lightning – be compliant with the standard
	Acoustics	Perception and preferences about noise- be compliant with the standards

The second table below contains possible recommendations on short-, medium and long-term actions to retrieve IEQ data and for modelling and integrating IEQ data into the Building Stock Observatory.

Further tasks and steps

Further next tasks of the workgroup are:

- Task 1: Prioritize indicators according to a set of criteria (e.g. health, comfort and well-being)
- Task 2: evaluate available data in a wish list, mapping a prioritized indicator list against available data sources
- Task 3: specify data needs/gaps and ways to cover them on short term and long term including assessing reasons for non-availability of data (data exist but not readily available) or scarcity (e.g. high cost to generate specific data)

Task 1 and 2 will run in parallel. Task 1 is meant as a process which will feed data into BSO on long-term, and Task 2 is a proceed that will feed data in BSO on short term.

Concluding the workshop, the following step were agreed by the participants:

- Step 1: define criteria to establish indicator priorities (e.g. health, comfort and well-being)
- Step 2: Drafting a template to collect information on the availability of indicators & data
- Step 3: integrate data from EU projects into the template
- Step 4: Complete the template on MS level. ■

Dimensions	Relevant data collection approaches	Specific references
Assets	Energy audit (Fin), EPC Database for large buildings (Portugal Energy Agency + other MS), environmental monitoring networks (outdoor), national radon observatories, WELL standards and voluntary certification schemes, Green Building Councils (each MS), market data on construction products and systems	
Measurement/modelling	Collaborative projects, national studies, publications, environmental monitoring networks (outdoor), national radon observatories, big data from building control systems	Officair, sinphonie, AUDIT, Insulate (Fin/Lt), Renovair (B), IPChem, Sinphonie-bis, HEALS, ref 1-10, Norman network, subtask 1 of annex 6
Perception	SILC survey, thermal comfort database; surveys organized by private companies, healthy home parameter, WELL standard	Officair, Renovais (B), OQAI (F)

SUSTAINABLE ENERGY WEEK

An initiative of the European Commission

REHVA high level policy session at EUSEW 2019

& highlights from the week

Report by **FATIMA AHMED, ANITA DERJANECZ, GIULIA MARENGHI, REBEKA MARSNJAK** & **MATTEO URBANI**

The European Sustainable Energy Week (EUSEEW) is the annual flagship event organised by the European Commission in the field of energy. In 2019, 14th edition focused on the theme 'Shaping Europe's Energy Future' with over 90 policy sessions, more than 4,000 registered participants, 380 speakers and 100+ unique networking opportunities. This year REHVA organized a successful high-level policy session "New EPBD: the value of actual performance and digitalisation". REHVA staff participated in many relevant sessions to report about the take-aways.

Opening session and messages to the next Commission

The opening session of the Policy Conference of the EU Sustainable Energy Week 2019 with a common topic on "Shaping Europe's energy future" started with the interventions of high-level EU policy makers discussing the current status and challenges of Energy Union. After **Miguel Arias Cañete**, European Commissioner for Energy and Climate Action opened the plenary session, **Dominique Ristori**, Director-General for Energy was moderating interesting panel discussions of national and EU level policy makers. The opening panel conveyed some messages to the next Commission, **Claude Turmes** called for an industrial vision for Europe to remain leader of the global energy transition, as well as working on European Green infrastructure projects and green investments. **Jerzy Buzek** (MEP EPP) stressed that the Energy Union is the most important European policy project and now it's time for its implementation. He called for a common European strategy on gas and a new gas market regulation. It is important to have a dialogue on energy transition between citizens and institutions, supporting smart city projects.

REHVA high level policy session *New EPBD: the value of actual performance and digitalisation*

On 19 June, REHVA organised a joint session of the official EUSEW policy conference of the Commission on cooperation with eu.bac (European Building Automation and Controls Association) and smartEn (Smart Energy Europe Association) with the title ***New EPBD: the value of actual performance and digitalisation***.

The session discussed regulatory and policy aspects, such as the role of EPB standards and the Smart Readiness Indicator, digitalization in buildings, performance monitoring and the role of smart buildings in the flexible energy system. The session focused on how to boost investor confidence in smart buildings to ensure the massive need for financing if Europe wants to deliver on the goal of a decarbonised building stock by 2050.

The session was opened by REHVA President **Frank Hovorka**, highlighting that investors need to trust the data on predicted and actual building performance and translate the output in terms of energy into cost and provide reliable calculation tools on decreased risk in the language of the bank sector. He sees the future solution in a dynamic EPC and building passport that displays also measures data on building performances covering energy, indoor comfort and ecological footprint at the same time.

Sylvain Roberts from DG Energy gave the EU policy background of the Clean Energy Package in his opening presentation, summarizing the key relevant points of the revised EPBD: the role of EPB standard, the problem of finance gap and how the Commission can help in boosting private investment, and the Smart Readiness Indicator that is meant as a tool to foster the deployment of smart buildings.

Johan Zirngibl (CSTB) introduced the voluntary certification tool developed by the ALDREN project. The aim is to foster energy renovation investment with a certification scheme that enables a common language between different stakeholders: building professionals, investors and building owners. The certification should consider beside energy efficiency indoor comfort and move towards operational performance to monetize non-energy related benefits convincing for investors and overs. This all should be integrated in the next generation of EPC-s and the building passports. ALDREN developed a pragmatic simplified IEQ indicator called TAIL, to assess the improvements before and after energy renovations.

Bertrand Deprez (Schneider Electric) closed the first session by giving some insights into the role of BACs in smart buildings and performance monitoring highlighting practical cases.

The presentation session was followed by a lively discussion moderated by **Michael Villa** (smartEn). A complementary panel of **Dick van Dijk** (EPB Center), **Bonnie Brook** (eu.bac/Siemens), **Caroline Milne** (Joule Assets Europe) and **Stefan Plesser** (synavision/QUEST project) discussed the different aspects related to the revised EPB: the rope of EPB standards, how to mow towards actual building performance by digitalization and technical monitoring, how to increase investors' confidence and the role of the SRI in the transition towards smart buildings.

Panel debate, Dick van Dijk, EPB Center (second from the left) highlighting the role of EPB standards.

REHVA high level policy session panel, Sylvain Roberts (DG ENER) presenting the revised EPBD.

Peter Hug closed the session with a well moderated Q&A session with the audience. Key take-aways from the discussions:

- EPB standards enable a systemic approach to calculate building performances a transparent way. However, as the EPB standards are voluntary and the EPBD can't make them mandatory, we need to promote the standards and encourage national governments to apply them. This is the mission of the EPB Center, to facilitate a step by step implementation.
- There is a lack of understanding on how financial institutions decide to invest in energy retrofit. There were no representatives from the financing sector among the audience, which shows that we need to put more effort in the exchange between building sector and financial sector experts.
- Investors can spend and huge amount of time on risk assessment in energy retrofit projects, especially if they need to aggregate small projects. There is a need for standardised tools and protocols that can translate technical performance assessment criteria into financial terms and language.

Energy renovation of the European building stock

EuroACE, the European Alliance of Companies for Energy Efficiency in Buildings orgnaised the session ***Implement, Industrialise and Imagine Future Buildings Renovation*** addressing the role and contribution of energy efficient building renovation in Europe's energy future in 3 time perspective:

- Implementation of the amended Energy Performance of Buildings Directive after 2020;
- Opportunities to invest more and industrialize the sector in order to accelerate actions by 2030;
- Imagining a strategic 2050 vision for a climate neutral economy and society with energy efficient buildings at its core.

Adrien Joyce presented the practical EuroACE guide to EPBD implementation[1] published last year. This guide shall serve as a strong support for EPBD to be better transposed and implemented at national levels and contains 12 high-level Recommendations and 5 main chapters that cover key issues of the new revised EPBD.

Corla Coyle presented good practices of implementing the EPBD in Ireland that follows a ambitious long-term renovation strategy. **Sibly Steuwer** (BPIE) reported on innovative solutions to upscale buildings renovation and highlighted the need for new business models, technical solutions to provide a smoother renovation process, enable appropriate trainings of auditors and building professional and to streamline financial solutions. **Remon Zakaria** (EBRD) presented the role of financial institutions and reported on financing instruments for green buildings that EBRD is offering such as Direct lending; Intermediated financing and Structured financing. Presentations and speaker information are available online[2].

The session ***Scaling up 2030 deep energy retrofit targets and the importance of a local framework for a socio-economic transition*** brought together seven EU Horizon2020 projects focusing on energy efficiency and building renovation, realizing the problem that, while similar projects address the same challenges, there is little information exchange and collaboration between them.

- **BuildHeat** tackled retrofitting of multifamily houses with a set of reliable, energy efficient and affordable retrofit solutions. The execution will be facilitated by industrialized, modular and flexible HVAC, façade and ICT systems developed
- **P2ENDURE** promotes evidence-based innovative solutions for deep renovation based on prefabricated Plug-and-Play systems in combination with on-site robotic 3D-printing and Building Information Modeling (BIM).
- **BRESAER** develops ad new concept of building envelope for residential buildings. Adaptable and modular prefabricated solutions for retrofitting for a flexible integration of the different components governed by an innovative Building Energy Management System
- **RenoZEB** unlocks the nearly Zero Energy Building (nZEB) renovation market by increasing property value through a new systemic approach to retrofitting. This will include innovative components, and processes and decision-making methodologies to guide all value-chain actors in the nZEB building renovation action

Adrien Joyce presented the guidance on the amended aspects of the EPBD launched by EuroACE.

1 https://euroace.org/wp-content/uploads/2018/11/EuroACE-Guide-to-EPBD-Implementation-web-version.pdf
2 https://www.eusew.eu/sites/default/files/programme-additional-docs/2019 EUSEW EuroACE Session - All Speakers Presentations.pdf

- **ReCO2ST** develops a Residential Retrofit assessment platform and demonstrates nearly zero energy and CO_2 emissions with cost optimal solution considering also health, comfort and environmental quality.
- **HEART** develops a multifunctional toolkit which integrates several components to transform existing buildings into energy efficient smart buildings
- **REZBUILD** developes a collaborative refurbishment ecosystem focused on the existing residential building stock and setting up a decision platform connecting key technologies and new business models

Panel debate - The green revolution starts at home.

The debate was a bridge to fill the knowledge gap among different stakeholders and support policy makers in tackling the barriers and leverage the opportunities of deep renovation thus facilitating a discussion that enabled the creation of synergies and possibilities to cooperate and share valuable knowledge. Its outcome focused on how inclusive policy discussions can foster technological innovation towards 2030 energy efficiency targets.

Innovative HVAC technologies

The green revolution starts at home session, organized by EHPA, addressed the need of awareness raising among EU citizens on the available best technologies for energy efficiency in buildings and stressed the importance having a solid network of qualified installers, builders and architects. Financing mechanisms are an important turning point as well, as a framework that involves local communities can provide the roadmap of socio-economic transition towards the 2050 energy targets. There is a need for strong political support to tackle the critical barrier of insufficient financing.

The session gave also a thorough overview of the heating and cooling sector in Europe with its opportunities, tools and technologies available for local, regional and national authorities. Europe consumes most of its energy to heat and cool households. More than 80% of the heat delivered to buildings coming from obsolete, inefficient and polluting boilers, thus, decarbonizing this sector is crucial. A steep increase in the current 20% share of renewables in heating and cooling is required, together with improving the efficiencies of heating and cooling systems to achieve the Paris Agreement goals. The solutions and technologies are already on the table such as heat pumps, district heating, cogeneration, biomass boilers and stoves, solar heat and geothermal energy. Moreover, various innovative tools and projects such as RELaTED, PLANHEAT and Hotmaps are being developed to assist cities and regions with the feasibility analysis, implementation phase and replication promotion of decarbonizing heating and cooling.

Financing sustainable energy investments

The session ***10 years of ELENA: grants to overcome barriers for sustainable investments*** presented key outcomes of the European Local Energy Assistance (ELENA), a joint initiative by the EIB and the European Commission under Horizon 2020. ELENA provides grants for technical assistance to plan and implement sustainable energy investments. It helps public and private authorities to tackle barriers in the preparation of sustainable energy investments and to bridge the gap between local and regional energy policies and project implementation. The session showcased the results of the programme on the occasion of its 10th anniversary. Five successful projects were presented:

- EOL (Ljubliana, Sl): a project focused on energy efficient renovation of public buildings using energy performance contracting;
- Picardie Pass Renovation (Picardie region, Fr): renovation of existing housing stock, based on the one-stop-shop approach;
- SCMC (Amsterdam, Nl): transport related project including investments in regenerative energy braking system for metro, electric buses, hybrid ferries and mobility related IT systems;
- L.E.U.V.E.N. (Leuven, Be): project related to the renovation of buildings (public and private), building integrated renewables and street lighting;
- EEFFRB (Pl): project promoted by a Polish Bank (BNP Paribas Bank Polska SA) related to the renovation of residential buildings. ■

The Chinese delegates in CLIMA 2019.

A short report on the REHVA-CAHVAC Workshop in CLIMA conference Bucharest 2019

GUANGYU CAO
Norwegian University of Science and Technology (NTNU), Norway

MANUEL GAMEIRO
University of Coimbra – Pólo II, Portugal

JIANLIN WU
Deputy Director, High Performance Building Research Center (HPBC)
Institute of Building Environment and Energy, China Academy of Building Research

China Innovation Alliance for Heating, Ventilation and Air-conditioning (CAHVAC) is the Chinese organisation, with approximately 40,000 members dedicated to advancing heating, ventilation, air conditioning and refrigeration to serve humanity and to promote a sustainable technology in China. In October 28, 2011, the first MoU was signed between CAHVAC and Federation of European Heating, Ventilation and Air-conditioning (REHVA), which represents, with its 27 member associations in Europe, more than 120.000 professionals in the area of HVAC. In the framework of the relationships between the two organizations, a delegation with more than 50 persons came from China to participate in CLIMA 2019 conference.

CAHVAC-REHVA workshop chaired by Prof. Manuel Gameiro da Silva, Vice-President of REHVA and Prof. Xu Zhang, Vice President of CAHVAC.

A CAHVAC-REHVA workshop entitled Energy in Buildings-Paths in Europe and China-Two Zooming Experiences was organized during the CLIMA 2019. It comprised, from each association:

1) A large scale presentation about energy markets, primary energy data, targets regarding energy efficiency and emissions, etc
2) A medium scale presentation about buildings and urban environment, where topics like smart cities, nearly zero energy buildings, nearly zero energy districts and integration of renewables may be addressed;
3) A micro-scale presentation related to indoor environmental quality, where monitoring web-based tools, human factors, the smart readiness indicator (for the European side) may be the topics for the presentation

In total, six presentations were done:

1) Nearly zero energy buildings in China – history, status and future, Wei Xu, President of CAHVAC, China Academy of Building Research, China
2) Numerical simulation and experiment investigation of phase change energy storage device in the heat pump assisted solar heating system. Yong Wang, Chongqing University, China
3) Radiant Floor Cooling and Applications in Airport Terminals. Xiaohua Liu, Tsinghua University,
4) Energy in Buildings in Europe: An Overview, Manuel Gameiro da Silva, Vice-President of REHVA, Chair of Education and Training Committee, University of Coimbra, Portugal
5) Ventilation and indoor air quality in healthcare facilities–practices and challenges. Guangyu Cao, Norwegian University of Science and Technology, Norway
6) Decentralized and centralized demand response control of district heating system in education building, Juha Jokisalo, Risto Kosonen, Aalto University, Finland

After the workshop, a new MoU was signed by Mr. Wei Xu, the president CAHVAC and Mr. Frank Hovorka, the president of REHVA. The purpose of this Memorandum of Understanding is to strengthen the relationship between REHVA and CAHVAC and to promote substantial and tangible actions to increase the co-operation between the two associations. ■

The ceremony of signing the MoU between CAHVAC-REHVA.

Report on the participation in CIAR 2019 Conference
in Santiago de Chile

Manuel Gameiro da Silva, in the sequence of an invitation in the framework of the MoU signed between FAIAR and REHVA, has represented REHVA in the CIAR 2019, the "XV Congreso Iberoamericano de Aire Acondicionado y Refrigeración", which was held from 8th to 10th of May 2019, in Santiago de Chile.

Before the congress, in the morning of the 8th of May 2019, it took place the General Assembly of FAIAR, in the headquarters building of the Chilean Chamber of Refrigeration and Climatization (CCRyC) with the presence of the delegations of the national associations' members of FAIAR. Manuel Gameiro da Silva has been invited to attend the meeting and to deliver an institutional presentation of REHVA. In the sequence of his presentation, the launch of a joint task force between REHVA and FAIAR, with the objective of reviewing the REHVA Guidebook 14 about Indoor Climate Quality Assessment has been addressed. There is a common interest of both federations in this topic, because there are two normative documents recently published (EN 16798-1 Standard and the proposal of an Ibero American Indoor Air Quality standard). It has been decided to start the process of the creation of a task force in the CLIMA 2019 conference in Bucharest during the REHVA TRC Meeting.

The congress has been very successful with the presence of more than 500 participants addressing very interesting topics in the HVAC area. In parallel a technical exhibition with the presence of important industrial companies and other institutions active in the area was also taking place in the congress venue. During the congress days the relationship between REHVA and ABRAVA, the Brazilian HVAC association were also addressed during informal meetings with the members of the direction board of this association.

The conference gala dinner, which provided very good opportunities to establish new connections with the delegates from all the Latin American countries present in the conference, represented a magnificent cultural activity with an outstanding travel through the dancing and singing traditions along the long Chilean territory.

Manuel Gameiro da Silva delivered also a scientific communication entitled "Evaluación y comunicación de la calidad ambiental en interiores" in a technical session of the congress about Indoor Environmental Quality. The support of the members of Atecyr board in the dissemination of REHVA vision and strategy during this congress should be gently recognized and acknowledged. ■

REHVA 2019 General Assembly

The 63rd REHVA General Assembly took place during the REHVA World Congress CLIMA2019 in Bucharest, Romania on Saturday June 25th, 2019.

After a welcoming address from the host, AIIR President Sorin Burchiu, Stefano P. Corgnati opened the REHVA General Assembly with the report on his mandate as a President of REHVA. Professor Stefano P. Corgnati as the 16th REHVA President 2016-2019 thanked to all the members of the board having contributed to his presidential term and left the stage to the new REHVA president Frank Hovorka who got elected for the mandate 2019-2022. Before that, Frank Hovorka was also a REHVA Treasurer and contributes to research projects on net zero energy buildings and on financial indicators of buildings "green value" (RICS, UNEP FI, IISBE and REHVA).

With a new presidential leadership, REHVA got new Board of Directors that joint Frank Hovorka in this presidential term. New REHVA Board members that got elected are the following: Manuel Gameiro da Silva, Kemal Gani Bayraktar, Juan Travesi, Ivo Martinac, Catalin Lungu and Atze Boerstra.

During the whole REHVA Annual meeting, the main strategic issues were discussed also during the REHVA Members Associations plenary meeting, Advisory meeting between Past Presidents and REHVA Committee bodies such as Supporters Committee, Technology and Research Committee, External relations Committee, Publishing and Marketing Committee and Cooperation Group. All REHVA Committees' Chairs presented their reports of activities, outcome and future goals.

Four important announcements during General Assembly were presented:

- REHVA Brussels' Summit, Belgium, 4-5 November 2019
- AM 2020, Lisbon, Portugal preceding CLIMAMED 15-18 May 2020
- AM 2021, Tallinn, Estonia preceding Cold Climate, 18-20 April 2021
- AM 2022, Rotterdam, the Netherlands preceding CLIMA 2022, 13-15 May 2022
- CLIMA 2022: Rotterdam, the Netherlands, 15-18 May 2022

This year after the REHVA Annual meeting, the CLIMA World Congress was held and brought together various experts, stakeholders and representatives of the different sectors to discuss latest technologies and developments toward zero-carbon economy in HVAC sector. ■

New REHVA Board: Manuel Gameiro da Silva, Kemal Gani Bayraktar, Juan Travesi, Frank Hovorka (President), Ivo Martinac, Catalin Lungu and Atze Boerstra.

Interview with our new Board Members of 2019

REHVA would like to congratulate its board members election at the Annual meeting General assembly. As board members of REHVA, we interviewed each newly elected person to discover their plans for contribution to the organisation, as well as their upcoming vision for REHVA.

Questions asked:

1) How has your background and experience prepared you to be an effective board member?

2) As a board member, what are the main changes you would like to make within REHVA?

3) In one sentence, how do you see REHVA in three years' time?

Kemal Gani BAYRAKTAR

Vice President, Turkey

1) I benefit my managerial and educational capabilities gained while working not only in NGOs with wide variety of disciplines such as Turkish Society of HVAC & Sanitary Engineers, International Solar Energy Society, IEA SHC and PVPS TCPs, but also in industry with different responsibilities. As being located in the Region where the continents meet and experiencing several societies in their different habitats, strengthening REHVA activities globally by developing collaborations with other organizations of our industries will be one of my priorities as well as contributing to achieve transform and growth in favour of REHVA mission and strategic objectives.

2) I would like to contribute to the development of interactions between our members, to increase joint projects together in line with SDGs and our objectives, to establish co-operations with other international organizations, to expand the borders of our value-added service worldwide.

3) REHVA will be serving to the globe for sustainability, health and well-being in cooperation with its multi-experienced and multi-disciplined members.

Ivo MARTINAC

Vice President, Sweden

1) With a background in mechanical and building services engineering, my main expertise is in the areas of indoor environment quality (IEQ) management, building performance management, high-performance building design-development-operation, as well as sustainable community and urban development. Over the years, special focus areas have included air filtration, IEQ management in commercial aircraft, resource-efficient hotel-/resort development and operation, building performance management, as well as energy system modelling for building clusters and districts. I have been a core member (Sweden) of REHVA's Technology and Research Committee since 2011 and coordinator (together with Andrei Litiu) for the Task Force "Smart Buildings" since 2018.

2) Increasing private-public HVAC-relevant research collaboration between REHVA Member Associations, ambitiously targeting eligible EU-funds (Horizon 2020 etc).

Enhancing the collaboration between REHVA Member Associations towards developing (certified and industry-recognized) life-long learning opportunities and programs for HVAC-professionals (study materials, guidebooks, physical and on-line courses etc).

3) We are currently facing an EU-wide shortage of state-of-the-art HVAC- & Energy-relevant expertise without which we will not be able to achieve the ambitious sustainable development goals set by the member countries and the EU.

Juan TRAVESI
Vice President
Spain

1) My main professional work is as consultant engineer. Therefore, I am a practitioner and I can provide the board my point of view on different aspects:

- Practical solutions on design and construction.
- Market situation on different markets (we work in other parts of the world, as Middle East)
- Regulations and standards situation and how deep are them involved on the practical work.

Besides this, I am also a professor in Architectural university in Spain. I teach at the bachelor's in architectural studies at IE University. Under this point of view, I can add what future architects can demand from REHVA.

2) REHVA should strongly increase the technical documentation in order to offer high quality and reliable information to the European engineers and architects. For doing that in a fast track, it is needed to explore different ways of collaboration between REHVA members to share their knowledge and documents. We are more than 27 Countries and there is much investigated and published but should be much more shared between us. REHVA should be the ambassador and link between our national associations and the world. If the technical activity grows keeping on high level our prestige will rapidly increase, and our association will grow in technical and political weight.

3) I see a strong REHVA with very good relations with other international associations, based in knowledge sharing and collaboration. ■

REHVA 2019 Annual Meeting Awards Highlights

During the Annual Meeting awards ceremony, held on the evening of the 25th May 2019, a series of awards were given to honourable members and fellows of REHVA.

Jaap Hogeling, from TVVL received a gold medal award in recognition of his outstanding services to REHVA and for his excellent contributions to science and engineering in heating, ventilation and air-conditioning. The REHVA Gold medal is a celebrated award. It is only granted once per year and given to the most dedicated and exceptional member of REHVA. Jaap has been an active member of REHVA for several years. He has been deeply involved in the successful implementation of our monthly REHVA Journals as Editor and Chief and is chair of the REHVA External relations committee.

The Night also followed with REHVA granting two new fellow awards in recognition of their significant contributions to REHVA, the board, the committees and to the task forces.

During the Annual Meeting awards 2019, REHVA had granted two new fellow awards in recognition of their significant contributions to REHVA, the board, the committees and to the task forces. The two new fellows whom were granted this special award were **Juan Travesi** from Spain and **Serafin Grana** from Portugal. REHVA would like to congratulate the two new fellows for their precious time and hard work.

Furthermore, two of REHVA's supporters were proud to receive their Special Supporters Award. REHVA congratulated **Halton** for its 50th anniversary and expressed its "heartfelt gratitude to Halton for being a true REHVA supporter for almost fifteen years". **Eurovent Certita Certification** also received an award as REHVA expressed its heartfelt gratitude to Eurovent Certita Certification for being a true REHVA supporter for almost fifteen years.

REHVA sincerely looks forward to continuing their strong collaboration with both organisations. ■

Jaap Hogeling receiving special Gold Pin from past president, Stefano Corgnati and current president Frank Hovorka.

From left to right: Juan Travesi and Serafin Grana receiving their Fellow Award from Past President Stefano Corgnati and Vice President Manuel Gameiro

Halton Group receiving a Special Supporters Award for its 50th Anniversary.

Eurovent receiving a Special Supporters Award.

CLIMA 2019 — Built environment facing climate change — REHVA 13th HVAC World Congress — 26 - 29 May, Bucharest, Romania

13th CLIMA Congress 2019 Overview

The CLIMA Congress which is the leading international scientific congress in the field of Heating, Ventilating and Air-Conditioning (HVAC) was held between the 26th – 29th May in Bucharest, the capital of Romania at the cities famous National Library, in which hundreds of participants from across the world attended the 3 day event to contribute and participate in the events topic: BUILT ENVIRONMENT FACING CLIMATE CHANGE.

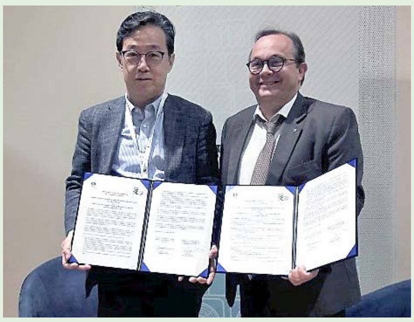
The topics greatly focussed on the event followed on Advanced HVAC&R&S Technology and Indoor Environment Quality, High Energy Performance and Sustainable Buildings, Information and Communication Technologies (ICT) for the Intelligent Building Management and Sustainable Urbanization and Energy System Integration.

Throughout the 3 days, the programme was packed with several sessions and workshops in which all participants were welcome to join in and contribute to, as well as the two REHVA courses for projects hybridGEOTABS and Nzeb design strategies that were taught in the first two days of the event.

During the evening, entertainment was provided to participants such as the AIIRs Presidents Dinner, as well as the traditional CLIMA 2019 gala dinner. ■

REHVA renewed Memorandum of Understanding with SAREK, SHASE, CAHVAC

During the REHVA Annual meeting and CLIMA 2019 in Bucharest, Romania, REHVA had a great opportunity to welcome our international partners and continue our future activities and cooperation. REHVA renewed MoU agreements with the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan (SHASE), Society of Air-conditioning and Refrigerating Engineers of Korea (SAREK) and China Innovation Alliance for Heating, Ventilation and Air-conditioning (CAHVAC). This cooperation is crucial to promote substantial and tangible actions to increase the cooperation, resulting in technological advancements and knowledge sharing. At the same time, to support each other's associations activities and to aim to jointly increase contacts with the international institutions. ■



Jin Chul Park, President-Elect of SAREK, with Frank Hovorka.

Professor Shin-ichi Tanabe, President of SHASE, with Frank Hovorka.

Professor Xu Wei, Chairman of CAHVAC, with Frank Hovorka.

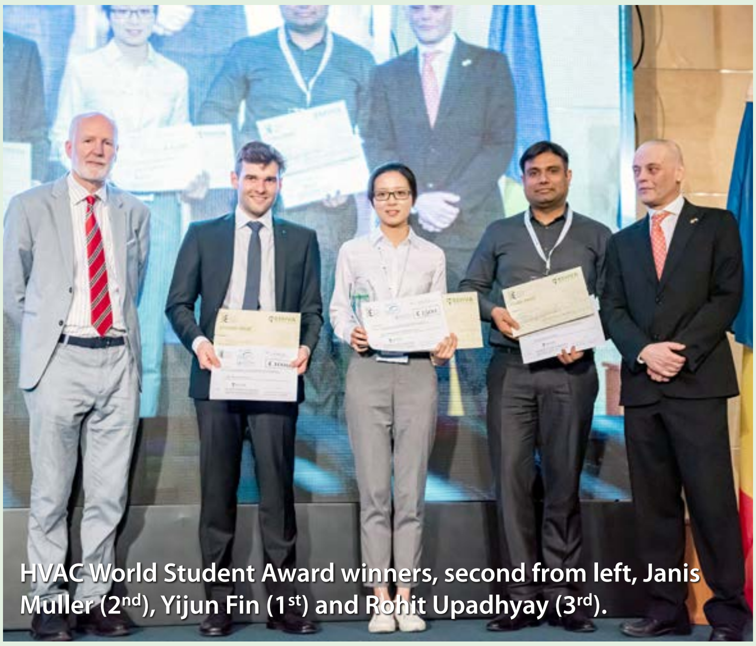
CLIMA 2019:
The REHVA Student Competition and HVAC World Student Competition: Highlights and Results

The REHVA Student Competition and the HVAC World Student Competition was held between the 26th – 29th of May at the CLIMA Congress 2019 where over 15 students had participated in the event.

The event begun with the REHVA Student Competition, with 15 participants showcasing several HVAC topics, and a jury of chairs judging the competition. The awards finally went out to 1 winner and 2 runner ups. **Janis Muller**, a German student from The University of Applied Sciences of Erfurt, whom focussed on the topic: Development of an adaptive aerofoil contour for use as a fan blade had won a first prize award of 1500 €, with two runners up, **Laura Nebot Andres** from Spain receiving a 2nd place position and a joint team from Denmark, **Michael Rosenlund** and **Yanting Li** in a respected 3rd place.

The REHVA Student Competition.

The HVAC World Student Competition had also been taken place the next day in which 6 students had participated. The award finally went out to **Yijun Fu** from the College of Environment and Building, University of Shanghai for Science and Technology, in China whom received a first-place prize for this topic: Research on Heat Transfer Characteristics of Carbon Dioxide in Microchannel, and Janis Muller receiving a second-place award for this competition. Third place went to **Rohit Upadhyay** from Canada who received this award.



HVAC World Student Award winners, second from left, Janis Muller (2nd), Yijun Fin (1st) and Rohit Upadhyay (3rd).

REHVA would like to congratulate all its participants within the competition for their hard work and efforts! ■

CLIMA 2019 workshops and courses

REHVA joint workshops

REHVA's involvement in the CLIMA 2019 congress continued the tradition to offer several practical, interactive workshops beside the plenary paper sessions. The workshops were organised by REHVA and its international sister associations, European research and innovation projects, as well as REHVA supporter companies representing leading HVAC manufactures and service providers.

During the three days of conferences and parallel plenary sessions REHVA staged as well joint workshops with different international and EU level institutions and associations: EPB Center, EPEE, EVIA, SHASE, eu.bac, ISIAQ and CCHVAC as well as joining partners from European projects for active participation.

The first day of CLIMA2019 started with the morning session of TripleA-reno and Mobistyle with the workshop "Why people matter? Exploitation strategies for people-centered design". The afternoon session then, showcased the SHASE-REHVA joint workshop "NZEB concepts in Europe and Japan" on the recent developments of nearly zero and zero energy requirements in EU and Japan, where the speakers, coordinated by the chairs **Jarek Kurnitski** (REHVA) and **Gyuyoung Yoon** (SHASE), focused on how energy performance requirements are set and how these can be compared so that climatic differences, national input data and calculation rules are taken into account. The parallel afternoon workshop "Supporting Dissemination and roll-Out of the set of Energy performance of Building (EPB) standards)" was then a detailed overview on the implementation of EPB policy at national level, through the collaboration between EPB Center, REHVA, EPEE and EVIA.

On the 2nd day of CLIMA2019, two parallel morning workshops opened the related program. The first joint sessions between CCHVAC and REHVA, titled "Energy in Buildings-Paths in Europe and Chine-Two Zooming Experiences" as well as an eu.bac and REHVA joint workshop "BACS supported performance, technical monitoring and certified commissioning of HVAC systems" was chaired by **Atze Boestra** (REHVA) and **Peter Hug** (eu.bac), were speakers presented the wide spectrum of tools and technologies supported by BACS to improve and optimize HVAC systems' performance and make it transparent to Building Owners/Operators.

The aim of this latter session was to inform the audience on the latest policy developments in the revised EPBD concerning technical building systems, with a focus on the key role of BACS functionalities. The European project hybridGEOTABS concluded the afternoon sessions with the workshop "Towards optimized performance, design and comfort in hybridGEOTABS buildings", chaired by **Lieve Helsen** (KU Leuven). The attendants had the possibility to learn the advantages of radiant heating and cooling systems from an energy and comfort perspective, and how these are designed in the

Jaap Hogeling at Workshop Supporting Dissemination and Roll-Out of the set of Energy Performance of Building (EPB) Standards


Pau Garcia Audi Policy Officer, DG ENER, European Commission at the Workshop Supporting Dissemination and Roll-Out of the set of Energy Performance of Building (EPB) Standards

context of the overall optimization of hybridGEOTABS systems, being introduced as well to innovative design procedures for these systems. And on the last day of the event, a REHVA joint sessions were closed with the workshop: "Evidence-based ventilation needs and development process of future standards", in collaboration with ISIAQ. The chairs **Jarek Kurnitski** (REHVA) and **Pawel Wargocki** (ISIAQ) coordinated the presentations towards research findings and their interpretation and meaning for ventilation system sizing, with the aim of establishing evidence-based design criteria of ventilation rates for residential and non-residential buildings.

REHVA courses

CLIMA2019 was also a great opportunity to launch two training courses, organized by REHVA, that deepened the nZEB design in the first day of congress and the hybridGEOTABS one (European project in which REHVA is active in the dissemination and communication activities) in the second day.

REHVA course 1: nZEB design: approach, principles and best practices

Stefano Paolo Corgnati and **Cristina Becchio** from Politecnico di Torino and **Cătălin Lungu** from Bucharest Technical University introduced the nZEB training course, where the design principles for an nZEB were not only introduced and discussed, but also their application examined by analysing successful case studies. The selection of the proper mix of energy technologies is the crucial issue in the design phase, and the cost optimal approach can be a powerful tool to compare solutions and select the best one.

REHVA course 2: How to design hybridGEOTABS buildings' components

hybridGEOTABS refers to the efficient integration of the combination of GEOTABS (GEOthermal heat pumps in combination with Thermally Activated Building Systems (TABS)) and secondary heating and cooling systems in a building.

Teachers **Lieve Helsen** from KU Leuven, **Qian Wang** from UPONOR, **Pieter Brepoels** from Viessman and **Hectro Cano Esteban** from GEOTER illustrated the key aspects of borehole design, heat pump requirements, distribution systems related to TABS and the potential of MPC in this new approach. The aim was to introduce to the attendees the design and optimization of the borefield from an economical and security of thermal supply point of view, the construction and system integration of TABS, the advantages of TABS and its suitable application in the respective building type and energy systems. ■

HEALTH AND ENVIRONMENT ALLIANCE

"Healthier Air, Healthier Children" HEAL Report Release on investigation of indoor air quality across primary schools in six Capitals

The Health and Environment Alliance has recently released a report "**Healthy Air, Healthier Children**" [1] on the air quality around primary schools across six European capital cities. The cities are London, Berlin, Madrid, Paris and Sofia and Warsaw. As primary schools in capitals are largely exposed to pollution in the air, a new policy must be taken for action at the local and EU level to protect the harm and risk of health of children. The report will link health and energy efficiency in schools to create a more climate friendly public building for schools across Europe.

The report involved a series of experiments, which involved school academics, such as teachers and pupils to push awareness to the impacts of air pollution in their city, as schools are widely targeted to pollutants entering the building from the streets and busy roads.

Upon monitoring the building, HEAL released results which had proved that there were high levels of CO_2 in the classrooms which indicates that ventilation systems are strongly required within these classrooms.

The reports that are readily available to read now, are for cities London [2], and Madrid [3].

You will also be able to find the rest of the reports for the 4 other cities in September 2019. ■

References with QR-codes:

[1] https://www.env-health.org/wp-content/uploads/2019/06/HEAL-Healthy-air-children_EU.pdf

[2] https://www.env-health.org/children-at-risk-of-day-long-exposure-to-polluted-air-inside-and-outside-london-classrooms/

[3] https://www.env-health.org/citizen-science-monitoring-of-air-quality-in-and-around-madrid-schools-confirms-the-need-to-cut-air-pollution-from-transport/

Flow sensors, DN 65 to DN 150

Flow sensors by Belimo for nominal diameters DN 65 to 150

More safety and efficiency in your system

The reliable flow measurement is crucial for the energy-efficient optimisation of HVAC systems. Sensors from Belimo utilise the ultrasonic transit time method to provide accurate and repeatable flow measurements for water and water-glycol mixtures throughout the entire temperature range from –20 to 120°C.

A special benefit of the new flow sensors is their glycol compensation. Reliable flow measurement is ensured by the ultrasonic measurement with patented procedure for recording, measuring and automatic compensation of the glycol concentration in the system. In addition, the sensor always calculates the correct density and specific heat capacity, which means no additional glycol sensor is required nor an additional measurement of the glycol concentration.

The sensor is made of corrosion-resistant materials and is insensitive to dirt due to the ultrasound measuring principle. With its robust and durable design, the flow sensor is protected against dirt and magnetite and is thus maintenance-free. This enables a higher long-term stability of the measurements and only minimal temporal deviations in the flow measurement in systems with high concentrations of dirt and magnetite. Another significant benefit of the new flow sensors from Belimo is the compact design of the sensor tube and sound converter. Due to their compact size the flow sensors save a lot of space.

In order to ensure a higher energy efficiency of the system, the Belimo sensor has been designed so that there is a low pressure drop at the sensor. That reduces pressure losses in the hydraulic system, further increases the energy efficiency of the system, and guarantees reliable operation and a long service life.

The flow sensors with nominal diameters from DN 65 to DN 150 are available since June 1, 2019. ■

For more information, see **www.belimo.com**

Send information of your event to Ms Giulia Marenghi gm@rehva.eu

Exhibitions, Conferences and seminars in 2019-2020

Exhibitions 2019

3-5 September	ISH Shanghai & CIHE	Shanghai, China	https://www.hk.messefrankfurt.com/content/ishs_cihe/shanghai/en/visitors/welcome.html
2-5 October	ISK-SODEX 2019	Istanbul, Turkey	www.sodex.com.tr/en
21-23 November	REFCOLD	Hyderabad, India	http://www.refcoldindia.com/

Conferences and seminars 2019

12-15 July	ISHVAC 2019 - 11th International Symposium of Heating, Ventilation and Air-Conditioning	Harbin, China	
18-22 August	ISIAQ	Kaunas, Lithuania	http://isesisiaq2019.org/
24-30 August	ICR 2019 - 25th IIR International Congress of Refrigeration	Montreal, Canada	https://icr2019.org/
2-4 September	Building Simulation Conference 2019	Rome, Italy	www.buildingsimulation2019.org
5-7 September	IAQVEC 2019	Bari, Italy	www.iaqvec2019.org
26-28 September	Annual Meeting of VDI-Society for Civil Engineering and Building Services	Dresden, Germany	
3-4 October	PZITS 100th Anniversary - Workshop - 'Practical side of sanitary installations and netwrosks designer and appraiser'	Warsaw, Poland	http://pzits.pl/100lat/gala-jubileuszowa/
15-16 October	AIVC 2019 Conference - From energy crisis to sustainable indoor climate	Ghent, Belgium	https://www.aivc2019conference.org/

Exhibitions 2020

27-29 February	ACREX	New Delhi, India	http://acrex.in/home
10-13 March	SHK Essen	Essen,Germany	https://www.shkessen.de/branchentreff/

Conferences and seminars 2020

14-17 June 2020	NSB 2020 Building Physics Conference	Tallinn, Estonia	www.nsb2020.org/

ISH Shanghai & CIHE 2019

The industry-leading platform for the HVAC and home comfort market in East and Central China

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Those companies looking to tap into the emerging HVAC and home comfort markets in China won't want to miss ISH Shanghai & CIHE 2019, held in Shanghai this 3 – 5 September. Following the ISH Beijing fair which took place in May, the Shanghai event allows suppliers to reach more buyers from the Eastern and Central areas of China. And like the Beijing event, energy saving products at ISH Shanghai will be in high demand following a raft of environmental protection policies that have been enacted by the Chinese government in recent years.

ISH Shanghai & CIHE will be held concurrently with the Shanghai International Lighting Fair, Shanghai Intelligent Building Technology, Shanghai Smart Home Technology and Parking China. Collectively, the fairs will host around 650 Chinese and global brands and expect to welcome some 60,000 trade buyers from around the world. It is the ideal platform for manufacturers, distributors, construction and installation companies, real estate developers and designers to explore new business opportunities in the Chinese and wider Asian markets.

European Pavilion

International brands are keen to tap into the HVAC market in East and Central China, which is one of the world's biggest emerging markets. The European Pavilion will again return to ISH Shanghai & CIHE with a stronger line-up of exhibitors to create a gateway for overseas brands to explore the ample business opportunities in China. Leading HVAC companies from Germany, Italy, France and elsewhere will present state-of-the-art technologies and exceptional technical skills from Europe.

Premium Area – four themes to showcase latest product trends

To cater to the specific market needs of East and Central China, a Premium Area will be featured again at this year's fair. Premium brands from China and overseas will showcase outstanding home comfort products and technologies under the following four themes:

- Technology
- Quality
- Design
- Technical Skills

The area will be an arena of innovative heating solutions, practical installation skills, stylish designs and high-quality products. Agents, distributors, developers, design institutes, engineering project-based buyers and end-users can easily navigate and find products and solutions to meet their specific needs.

Coal-to-clean energy policy: ample business opportunities in China's HVAC market

Following the government's efforts in promoting clean energy heating, market users in East and Central China are becoming increasingly conscious of pollution-free HVAC solutions. These developments are creating higher demand for energy-efficient heating systems. Leading brands are quickly adapting to this fast-changing industry landscape by developing more energy-efficient heating solutions.

Home comfort systems: Future-proof smart integrated solutions

Home comfort systems including heating products (wall-hung boilers, heat pumps, water heaters and

more), fresh air, air conditioning, ventilation, water purification systems, dehumidifiers and intelligent controls are becoming increasingly popular in East and Central China. ISH Shanghai & CIHE is committed to helping global manufacturers, distributors, developers, designers and engineers capture the vast business opportunities generated.

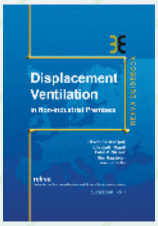
Concurrent events highlight future developments in East and Central China's HVAC industry

A diverse array of concurrent events makes ISH Shanghai & CIHE an ideal hub for high-level technical presentations and discussions. The Chinese government has been strengthening the promotion of energy conservation and emission reductions, hence the Shanghai International HVAC Forum will feature industry experts sharing their vision for the future of the HVAC and home comfort markets in East and Central China. ■

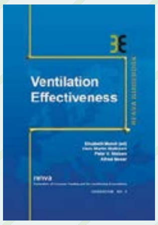
To find out more about the fair, please visit
https://ishs-cihe.hk.messefrankfurt.com/shanghai/en.html

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

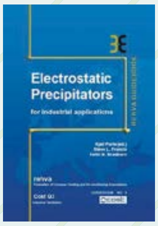
EUROPEAN GUIDEBOOKS



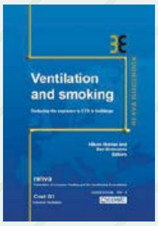
No.01: DISPLACEMENT VENTILATION IN NON-INDUSTRIAL PREMISES



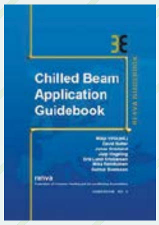
No.02: VENTILATION EFFECTIVENESS



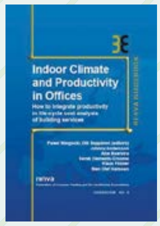
No.03: ELECTROSTATIC PRECIPITATORS FOR INDUSTRIAL APPLICATIONS



No.04: VENTILATION AND SMOKING

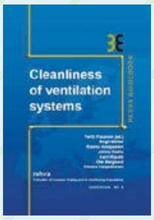


No.05: CHILLED BEAM APPLICATION GUIDEBOOK



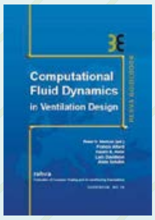
No.06: INDOOR CLIMATE AND PRODUCTIVITY IN OFFICES

No.07: LOW TEMPERATURE HEATING AND HIGH TEMPERATURE COOLING

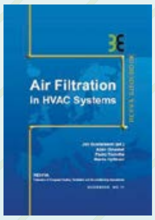


No.08: CLEANLINESS OF VENTILATION SYSTEM

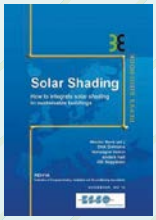
No.09: HYGIENE REQUIREMENTS FOR VENTILATION AND AIR-CONDITIONING SYSTEMS



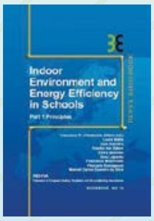
No.10: COMPUTATIONAL FLUID DYNAMICS IN VENTILATION DESIGN



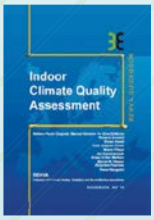
No.11: AIR FILTRATION IN HVAC SYSTEMS



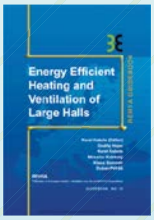
No.12: SOLAR SHADING



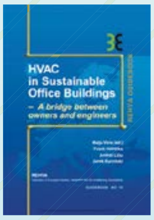
No.13: INDOOR ENVIRONMENT AND ENERGY EFFICIENCY IN SCHOOLS - PART 1 PRINCIPLES



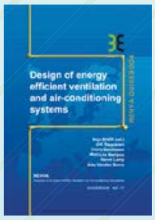
No.14: INDOOR CLIMATE QUALITY ASSESSMENT



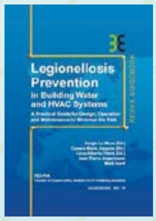
No.15: ENERGY EFFICIENT HEATING AND VENTILATION OF LARGE HALLS



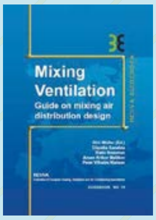
No.16: HVAC IN SUSTAINABLE OFFICE BUILDINGS



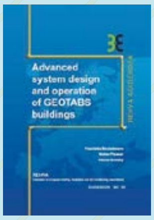
No.17: DESIGN OF ENERGY EFFICIENT VENTILATION AND AIR-CONDITIONING SYSTEMS



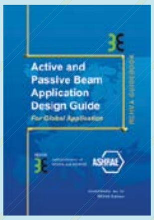
No.18: LEGIONELLOSIS PREVENTION IN BUILDING WATER AND HVAC SYSTEMS



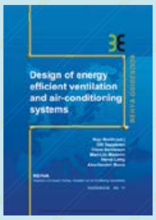
No.19: MIXING VENTILATION



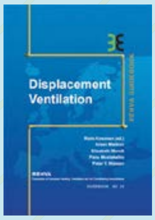
No.20: ADVANCED SYSTEM DESIGN AND OPERATION OF GEOTABS BUILDINGS



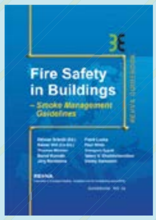
No.21: ACTIVE AND PASSIVE BEAM APPLICATION DESIGN GUIDE



No.22: INTRODUCTION TO BUILDING AUTOMATION, CONTROLS AND TECHNICAL BUILDING MANAGEMENT

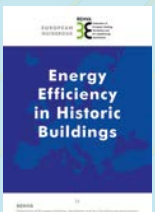


No.23: DISPLACEMENT VENTILATION

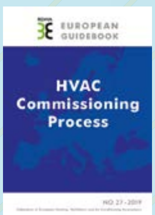


No.24: FIRE SAFETY IN BUILDINGS

No.25: RESIDENTIAL HEAT RECOVERY VENTILATION



No.26: ENERGY EFFICIENCY IN HISTORIC BUILDINGS



No.27: HVAC COMMISSIONING PROCESS (REHVA-ISHRAE)

No.28: NZEB DESIGN STRATEGIES FOR RESIDENTIAL BUILDINGS IN MEDITERRANEAN REGIONS

No.29: QUALITY MANAGEMENT FOR BUILDINGS