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The HVAC sector has to act now!

JAAP HOGELING
Editor-in-Chief

The latest report from scientists at the Intergovernmental Panel on Climate Change (IPCC) state that warming beyond 1.5°C will have frightening consequences. Only a global transformation, beginning now, will avoid this! In a major report [1] released October 8th 2018, the UN's climate science body reported that limiting warming to 1.5°C, compared to 2°C, would spare a vast sweep of people and life on earth from devastating impacts. To achieve this 1.5°C target the carbon pollution must fall to 'net zero' in around 30 years. This is a huge and immediate change. Not many governments have shown action programs to reach this reduction level so far. **The next few years are probably the most important in our history**.

The European Commission reported in September that net zero emissions can only be achieved by 2050 if member states develop more innovative, cross-sectoral, and '**beyond business-as-usual**' scenarios. Important dates for our policy makers:

- **28 Nov. 2018**: European Commission expected to release its draft long-term climate strategy for 2050;
- **2019**: EU governments expected to agree on the EU's final long-term strategy for 2050.

However, we should not wait for those policy discussions. The question is not about technology. We have the tools we need. Renewable deployment would need to be six times faster than it is today, said **Adnan Z. Amin**, the director general of the International Renewable Energy Agency. That was "technically feasible and economically attractive", he added.

How can we as HVAC professionals contribute? First by removing all unnecessary barriers, apply the best available technology. If energy for HVAC is needed it is up to us professionals to think holistic, which may imply that we defer some renovation budget to first reduce the energy need by thermal insulation, airtightness measures and passive solar. The holistic approach means also combining energy use and production in a smart way. The set of EPB standards developed to support the implementation of the EPBD reflects this holistic thinking (see [2]). Thinking out of the box and offering our customers the most innovative and sustainable possible solution. This is our duty and responsibility. In most cases just repeating our existing technical solution is no option. We have to invest in our innovative power and convince our clients that it is also in their future generation interest. We have the tools and knowledge, yes, we should act now. Depending on the projects BIM, Ecodesign product requirements, proper EPBD implementation at national level will support these actions. ■

[1] http://www.ipcc.ch/report/sr15/
[2] www.EPB.center


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BIMplement

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Introduction to the H2020 BIMplement project

Towards a learning building sector for enhanced quality control by setting up a qualification methodology integrating technical, cross-trade and BIM related skills and competences

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To improve the current situation and accelerate the rate and quality of nZEB construction and renovation, the European Commission took the challenge supporting several initiatives including H2020 Construction Skills funding schemes. This paper introduces the H2020 Construction Skills project BIMplement, explains its vision and how utilizing BIM to improve skills of different professions can lead to an improved quality and enhanced quality control over entire value chain. The overarching project goal is to achieve an improved quality for nearly Zero Energy Building (nZEB) construction and renovation by using BIM as a universal information carrier and enabler of the learning process within projects and between projects.

Keywords: Quality control, BIM, skills, competences and upskilling, qualification schemes.

Motivation

Given that about 75% of the EU building stock is considered energy inefficient and the energy use in buildings (residential and commercial) is responsible for about 40% of final energy consumption in the European Union [1], energy efficiency renovation represents a promising long-term growth possibility for the EU construction sector. Nevertheless, construction industry is seen as being relatively inefficient in both process and service delivery. There is evident gap between the designed level of energy efficiency and the level of energy efficiency realized [2] also due to a lack of built quality and skills gap. The construction sector suffers from a lack of skilled workers in general, while energy efficiency renovations even requires additional competences and qualifications. According to the World Economic Forum, construction labor productivity has stagnated over the past 50 years [3].

This shows that nearly Zero Energy Building (nZEB) construction and renovation need an enhanced systematic approach for the quality control of the entire process. An enhanced quality control approach can only be achieved by a fully qualified and equipped workforce, capable to implement, execute and perform all the necessary actions with a full understanding of the responsibility of their own profession and actions, as well as the relation with the other involved professions and actions within the value chain.

Why to implement BIMplement?

With objectives to improve knowledge, skills and competences of all the relevant disciplines involved in nZEB construction and renovation, and create more collaboration between them, the BIMplement project was funded. The BIMplement is a 30 month-long EU funded project involving 10 partners from 5 different countries: France, the Netherlands, Lithuania, Spain and Poland which started in September 2017.

BIMplement origins - PROF/TRAC project

One of the first projects contracted under H2020 Construction Skills was PROF/TRAC: 'Professional multi-disciplinary Training and Continuing development in skills for nZEB principles' (2015–2018), www.proftrac.eu which is also the foundation for BIMplement. REHVA was one of the core partners in this project; moreover, four national REHVA members were involved in PROF/TRAC as national training providers (ATECYR, DANVAK, HKIS, TVVL).

The overall objective of PROF/TRAC was to develop a European training and qualification scheme as part of a life-long learning process for continuous development and up-skilling of professionals, aiming at middle and senior professionals with a higher education degree (white-collars). The collaboration in PROF/TRAC with European organizations like REHVA, Architect Council of Europe and Housing Europe turned out to be an important prerequisite for the implementation of the results as it appeared to be very effective both for endorsement and for a further European roll out as their national members can act as training providers.

BIMplement builds upon the PROF-TRAC project as also several BuildUp Skills projects (FR, NL, LT) where these project's results and successes offer the necessary building blocks in training, CPD, methodologies for skills mapping (http://proftrac.eu/training-materials.html;) for all professions and for levels involved in nZEB skills.


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BIMplement - the road towards an improved quality for nZEB in Europe

BIMplement engages further and tackles remaining challenge on how to make a major step forward in the implementation of these qualifications where BIM can offer the competitive advantage as an efficient management strategic tool and as such, gives an opportunity to implement results in a BIM-enabled workplace learning environment. This is done in a cross-cutting process that is:

- Cross-trade: with a multidisciplinary approach throughout the entire value chain of the buildings sector.
- Cross-European Qualification Framework (EQF) -level: addressing both blue-collar workers, middle and senior level professionals.
- Cross-time: by setting up a flexible qualification methodology so that new innovations and uses of technologies can be addressed.
- Cross-country: by setting up a mutual recognition scheme of qualifications among different Member States, but by leaving room for Member States specific roles and uses of technology
- Cross-value: by improved appreciation of the end user's needs including the quality of indoor environment (thermal and visual comfort, acoustics, air quality, etc.), in an improved operation and maintenance by closing the learning loop using BIM as information carrier.
- Cross-size: from SME to Enterprise, based on regional of local experience centres or BIM-Hubs.
- Cross-project: by using BIM as a learning environment, to facilitate and enable the learning flow.

In this way BIMplement paves a road towards an improved quality for nZEB construction and renovation by the following objectives:

- addressing the entire value chain of the building sector and the total construction process (from pre-design to in use phase);
- improving skills of professionals as blue-collar workers for nZEB quality (cross-trade & cross-level) via large scale trainings and continuous professional development (CPD);
- developing a flexible qualification methodology that is able to anticipate new products and processes (cross-time) in different countries (cross-country);
- empowered by BIM and BIM enhanced workplace learning tools.

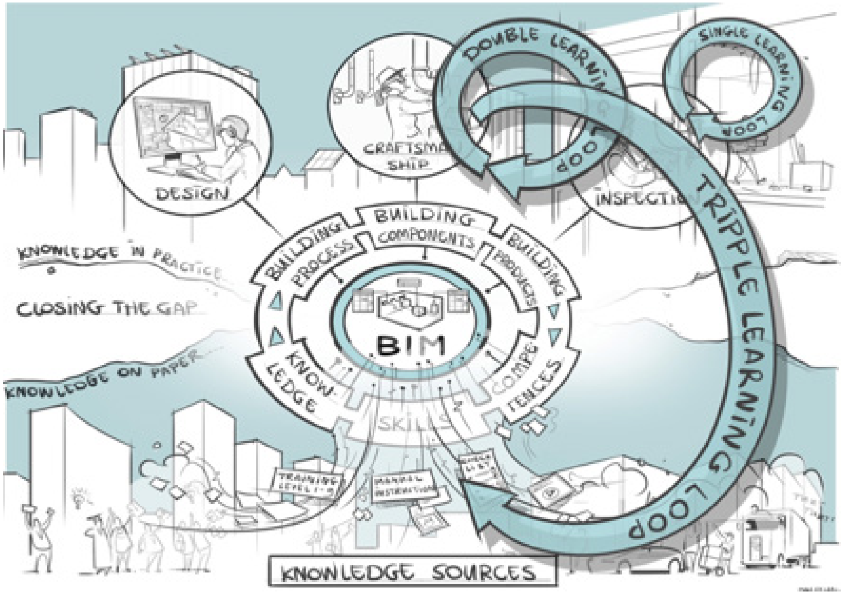

Figure 1. The BIMplement methodology aims to close the gap between the knowledge in practice and knowledge in paper by creating various learning and knowledge exchange loops, supported by adequate quality control.

Towards enhanced quality control over entire value chain by using BIM

The four BIMplement steps present a journey towards the upgrade of the quality of the work needed to meet nZEB targets.

Step 1: BIMplement methodology development with tools and learning content, using BIM as an information carrier

The project started with the development of a flexible qualification methodology to standardize the needed qualifications and a range of learning tools, to unlock and implement these qualifications. By using a systematic standardized approach, the mapped qualifications are to be transparent and comparable between EU member states, thus facilitating and providing EU mobility; robust and flexible (dynamic) approach for national adaptation. Also, as the evolution of technologies and materials is rapid, the methodology requires continuously reconsidering and updating our knowledge and skills.

BIMplement develops a general BIM-enhanced qualification framework (QF) structure and method to identify the different professions and professional levels for the specific crucial topics for nZEB technologies, concepts, products, as a function of the phases in the construction process. It is adaptable for blue and white collar-workers and professionals, with an implementation within existing learning tools and methodologies. This is based on PROF/TRAC Qualification scheme framework while utilizing BIM to connect the knowledge sources with the building process, building components and building products. The methodology building upon existing BIM process structures (CEN/TC 442 Building Information Modelling (BIM)) and existing classifications (e.g. IEC 81346 and ISO TC 59/SC 13/WG 11: ISO 16757 Data structures for building services product catalogues) where the BIMplement didactical task descriptions for the addressed technologies and components are then linked with suitable education material and trainings on a national level.

Step 2: Testing the methodology by implementing it for two specific areas: air-tightness and ventilation

To keep focus within the project itself, the testing of the methodology is dedicated to the implementation of ventilation systems and ensuring the air-tightness of buildings. As for the ventilation, there can be a didactical task connected with the BIM object or technology. Nevertheless, air-tightness is a more complex building application area as it is related to almost all the different building envelope components (transparent as opaque) as to joints application in-between. Therefore, air tightness should be assessed more holistically with objective to control air leakage and heat losses through the building fabric and at interfaces, joints & junctions.

Step 3: Pilots demonstration and validation

The objective of the BIMplement is to apply the methodology in 50 experimental sites (in NL, PL, LT, SP, FR) leading to upskilling 200 white collars and 1000 blue collars in 30–35 construction and renovation projects in France, and others each executing about 5 projects. The learning methods and the qualification schemes are connected to the projects defined in the pilot field labs and the experimental sites, this in order to improve the quality of the involved white- and blue-collar workers and thus, improving the overall quality of the construction process.

The methodology is implemented in collaboration with BIM-learning centres or national BIM experts where several objectives are to be achieved as presented in **Figure 2**.

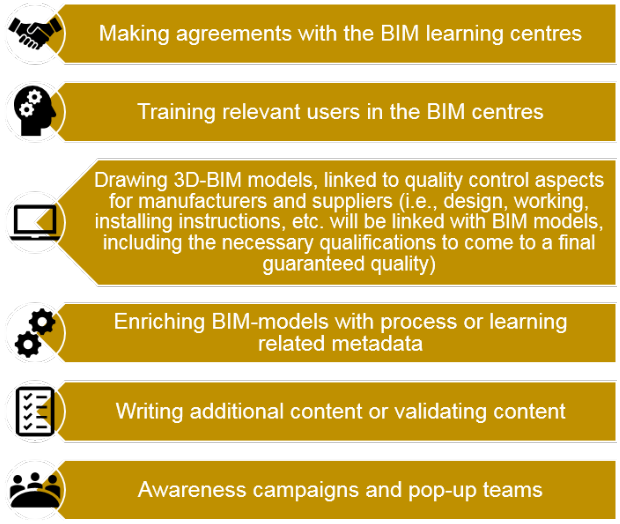

Figure 2. Implementation strategy of the BIMplement methodology in 'real' construction projects.

First BIMplement trainings already took place in France

Read about the feedbacks from the BIMplement implementation sites:

In France, the one-day BIMplement training took place on the construction site of an office building at Saint-Nicolas-lez-Arras attended by 16 managers and white-collar workers from 14 companies involved in the works; 3 representatives from the client (KIC, a private office builder) and from the third party responsible for building control inspections; 1 BIMplement coach and 1 future 'BIMplement master trainer'. The comments of the participants confirm the interest of this training, as show these witnesses:

- Client's employees, KIC, had to convince the enterprises to come to the training where they expressed at first several concerns: *'I was quite afraid before, because I was not sure that the companies would come to this training session. Most of them were reluctant, saying that they did not understand the interest of a training on BIM and related issues (airtightness and ventilation). But all of them came, and all of them were very satisfied with the training. We (KIC) plan not only to continue the BIMplement training at our Saint-Nicolas-lez-Arras site, but also to use BIMplement at the construction site of a 4.500 m² office building in Valenciennes (nearby Lille) next year'.*
- From managers and white-collar workers following feedbacks were received:

  'A very interesting training. I know now why and how the BIM model makes possible the positive interactions between the crafts…'

  'I discover that BIM is a beautiful tool to do a high-quality work… '

  'When you have high energy efficiency goals, BIM is of great help…'

  'I now see that BIM is the medium to solve the conflicts between the crafts at the workplace…'

Figure 3. First BIMplement training taking place in France, 2018.

Step 4: Exploitation and replication

In the end project's aims to ensure that more Member States and nZEB areas will benefit, while fostering further cross-border cross-sector developments on a lasting basis. The lessons learned from the 'pilot field labs' and the 'experimental sites' will be capitalized, together with the tools and learning methods developed. To this effect, last phase of the project covers further exploitation and replication of the project results to increase the number of skilled building professionals and craftsmen across the building value chain through spillover effect. The projects replication and exploitation strategy aims at deliberate efforts to increase the impact of successfully tested innovative qualification and training schemes.

Figure 4. From BIMplement methodology to BIMplement in practice.

Conclusions so far and recommendations for future

After the mapping of existing knowledge sources was done on a national level, it seems there is sufficient knowledge to deliver quality. However, the problem is that the availability just on time and fit for purpose is very poor. As tested in BIMplement, utilizing BIM allows storing relevant learning and process metadata in an efficient way. Secondly, BIM can be enriched with quality levels, needed skills and linked trainings. In this way, BIM can serve as a multidisciplinary data repository. Enhancing or connecting BIM models with didactical information can enable and facilitate the learning process over the whole value chain. Thirdly, BIM can improve a collaboration between different disciplines and management of works allowing synchronization of design and construction phase. In the end, in BIMplement BIM on its own is not the goal but improved quality for nZEB construction and renovation and a more efficient systematic process are the goals. At the moment the best approach to reach these goals seems to be using BIM.

To conclude, the construction sector is one of the main pillars of the EU economy where the construction industry is one of the largest European industries with 9% of the GDP of the EU [4] and 18 million jobs and 3.1 million enterprises [5]. Innovative solutions within digitalization of the construction industry such as BIM, can respond to the sector's challenges as are lack of skilled workforce, energy efficiency and lagging productivity. On this matter, energy efficiency cannot be reached without sufficient quality and no quality without qualified workforce. As the practice shows, to obtain sufficient qualified workforce upskilling and trainings are required and this is where BIMplement comes in play. ■

Acknowledgement

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References

[1] European Commission, EASME, Buildings. URL: Available online: https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings (accessed on 25.09.2018).

[2] P. de Wilde, 2014. *The gap between predicted and measured energy performance of buildings: A framework for investigation*. Elsevier, Automation and Construction, Volume 41, Pages 40–49. https://doi.org/10.1016/j.autcon.2014.02.009.

[3] World Economic Forum, 2016. Shaping the Future of Construction: A Breakthrough in Mindset and Technology. Geneva: World Economic Forum.

[4] DG GROW, 2016. *Brochure – The European Construction sector, A global partner*. URL: Available online: https://ec.europa.eu/docsroom/documents/15866/attachments/1/translations/en/renditions/pdf (accessed on 25.09.2018).

[5] European Commission, 2016. Good practice in energy efficiency - For a sustainable, safer and more competitive Europe. URL: Available online: https://ec.europa.eu/energy/sites/ener/files/publication/version2-web.pdf (accessed on 25.09.2018).

PRODBIM Overview

Act of digitalization of construction products

Outlines of CEN TC 442 developments & ISO TC 59

BIM & Digitalization

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Overview on Building Information Modelling (BIM) & recent developments in construction Product digitalization & standardization.

The necessity to be INTERCONNECTED.

PRODBIM, as subsidiary of Eurovent Services Company and in association with REHVA, is participating in CEN TC 442 & BuildingSMART working groups, and is compiling a summary of what is necessary to understand in the digitalization of our HVAC-R industry. Interconnecting dictionaries is the first step!

State of the art:

Today, we have all understood that the construction industry is moving towards digital building twin and BIM models. Indeed, the Computer-Aided Design software have finally evolved in 3D like their pairs in automotive or aeronautics sectors many years ago. This impacts the whole value chain of the construction: from design, simulation, installation, and maintenance and it concerns all the actors: AEC (Architect/Engineering/Contractors) but also in the near future, the facility management and the final users, i.e. building owners.

In parallel, the web is accelerating the broadcasting of product catalogues along with the resellers.

Indeed, the information of our manufactured products will be integrated in the 3D models and will need to be exchanged in a digital format with the different users. Therefore, the traditional product documentation needs to be structured by product data. Many libraries are nurturing to propose local product databases and the web catalogues are proposing our manufacturers products online for product selection.

The main question then arises: how the product information will be manageable in this digital evolution. The standardization works carried out by ISO TC 59 & CEN TC 442 on our European perimeter are keys to address this main evolution, but it is to ourselves to set the common framework for our HVAC-R industry.

The digital standards landscape

Let's try to see clearly in these digital standards and regulations.

First, we have the Construction Products Regulation which sets harmonised rules on how to express the performance of construction product and CEN standards ruling products compliances (CE marking, DoP, method of measurement & testing…).

Secondly, we have new ISO & CEN standards to organize the information for the construction sector which embeds the building product information. The corresponding working groups and technical committees and projects are part of the following TC s:

The ecosystem of standards working groups in digital buildings can aso be represented as in **Figure 1**.

The building digitalization and the BIM

To explain easily what the construction and real estate sector is facing in the actual digitalization process is what happened in the automotive industry with the CAD drawing revolution.

The Building information modelling (or management), are the same faces of the digital transformation of the building sector: the CAD software can draw in 3D where the drawing contains objects with the geometry and information on the equipment and the building, and not any more vectors like Autocad 2D. Thus these objects become a class in Information Technology language, with data.

The Building information modelling, or management is a collaborative process where the different actors of the AEC and building sector industry can share simultaneously a 3D model and information within, as shown in the diagrams. This is a change and also in the lifecycle of the product in a building project.

Software editors gathered years ago to solve the question: how to put the information to be interoperable and machine-readable. They used comparable industrial IT methodology standards like EXPRESS-STEP and the Industry Foundation Class (IFC) was born!

In order for two software to read exchange information, we need a triangle of information:

1. a common terminology
2. a format
3. an exchange specification independent from native software languages

and an international association to coordinate these new ISO standards and the BIM development: here is the openBIM!

To explain the IFC structure, a class of an IFC object has been created to store the information of the project and elements based on EXPRESS or XML the common used web language. We are now in the IFC version 4, after the IFC2*3.

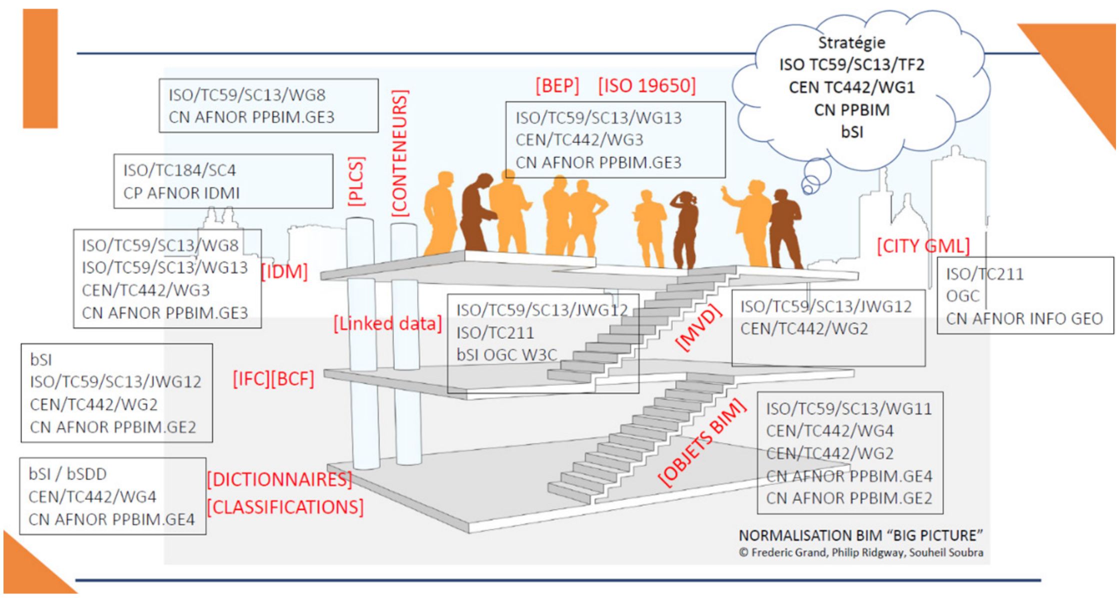


Figure 1. BIM Standardisation BIG PICTURE. (source AFNOR PPBIM)

Example of IFC structure, classes and relation extracted from Buildingsmart (**Figure 5a**,**b**,**c**,**d**).

In principle, a product is designed in a calculation software or 3D building model or pulled out of a BIM object library, which generates a compatible IFC file with geometry and parameters of the buildings and the different layers and objects. Levels of Details and Information are defined following the phase of the project and additional dimensions of information can be added (geometry, planning, cost, energy, maintenance…). The parameters of the object are translated in properties in IFC fields. A property is a feature of an object which can be generic with no brand name or a catalogue product in our case.

See example of the product integration in the BIM value chain: the manufacturer sends to the designer software its catalogue products or the designer selects in a library of regulatory products the required compliant products for its building project or thermal calculation. Then the objects and libraries are connected to the BIM CAD modellers with interfaces (APIs or plug-ins).

However, the critical task for each actor is to receive a product information to be able to map the information between the request and the response: i.e. If no common terminology is defined, how can our users and our manufacturers communicate?

Same for the product classifications, how to send product information to the local classification or required classification? Regulatory, standard, code, local requirements like thermal regulation, ETIM, Omniclass, Uniformat… and so many classifications coexist today but how to link my product data information with all?

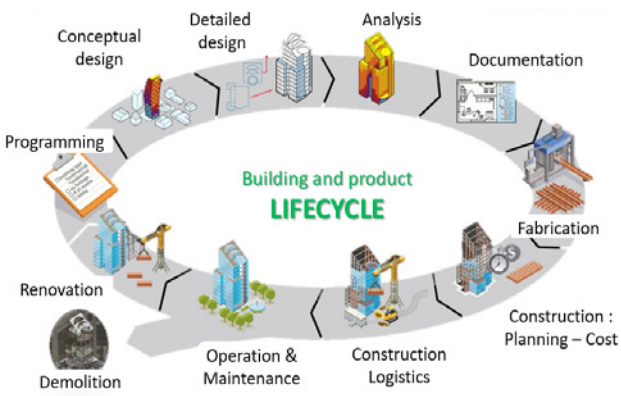


Figure 2. BIM lifecycle

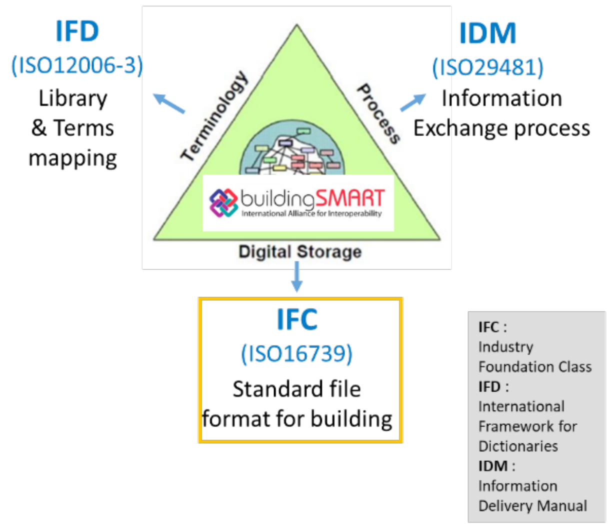


Figure 4. BIM standards diagram.

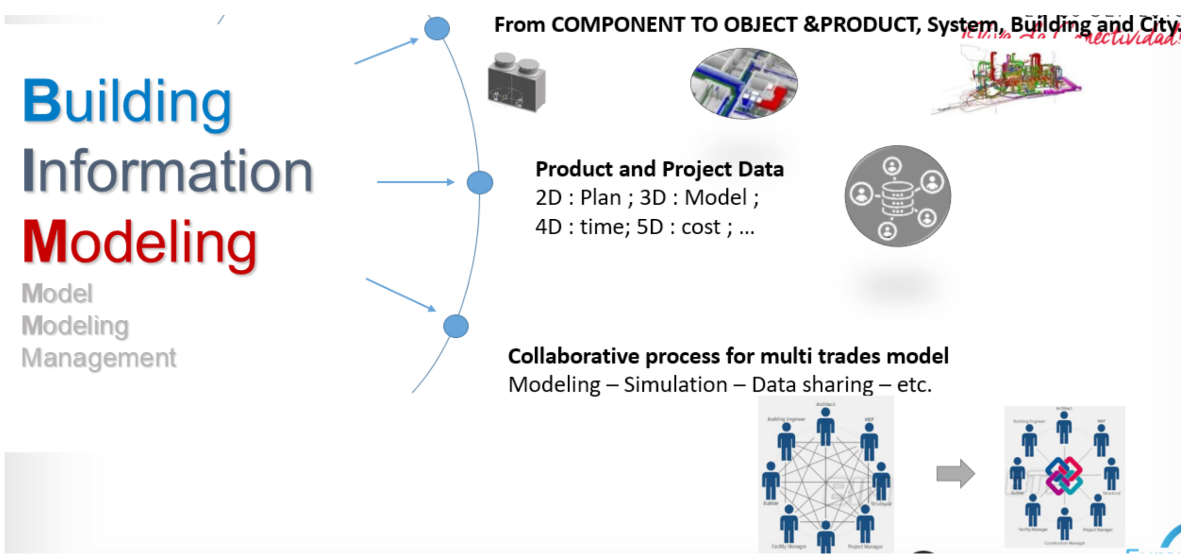


Figure 3. BIM diagram.

For the specific performance data, if we do not have the same definition of the product property, how a software can select a product list based on a performance or certification?

At last, if I have my official local dictionary of products in my country, how to link it with my other market in the neighbour country with the other local language dictionary?

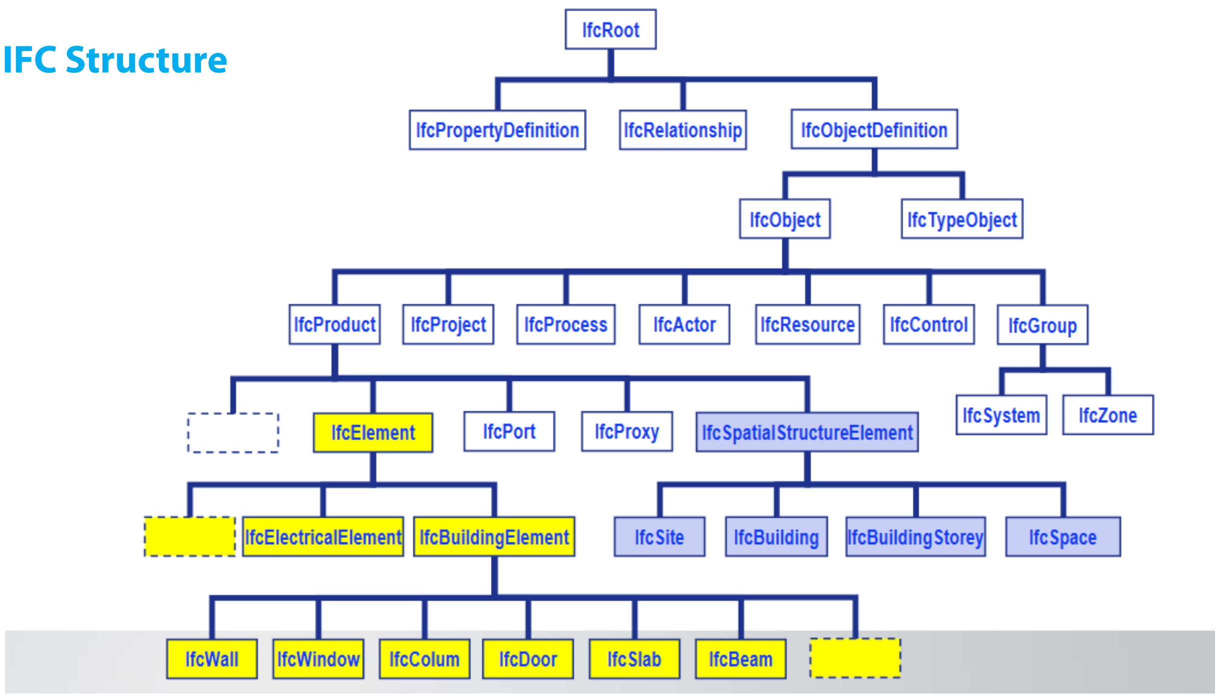
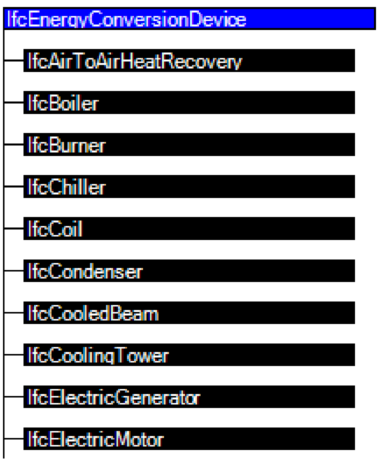


Figure 5a. IFC Structure



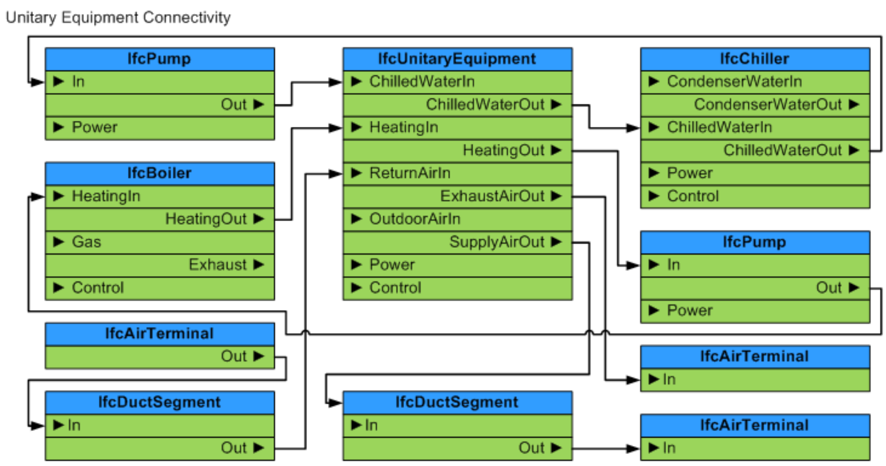


Figure 5b. Example IFC Objects.

Figure 5c. Example IFC object model.

```
- <PropertySetBind referenceId="simpleOptional">
  - <Rules>
    - <Include subtypes="true" entityType="IfcFooting">
      - <Where>
          <!-- Multible constraints are also possible. Using multible include rules alows optional constraints sets -->
          <!-- E.g., Any footing that is not made of concrete and has user defined field 1 set between 2 and 3, OR any
          footing that field 1 set to 1 and has user defined field 2 set between 0 and 42, except 10. -->
        - <Compare comparisonOperator="LessThan" xsi:type="IntegerCompareType">
          - <GetValue xsi:type="TemplateVariableType">
              <TemplateName>USER_FIELD_1</TemplateName>
            </GetValue>
            <ReferenceValue>4</ReferenceValue>
          </Compare>
```

Figure 5d. Example IFC XML file.

(Source: http://www.buildingsmart-tech.org/ifc/IFC2x4/rc2/html/schema/ifchvacdomain/lexical/ifcunitaryequipment.htm)

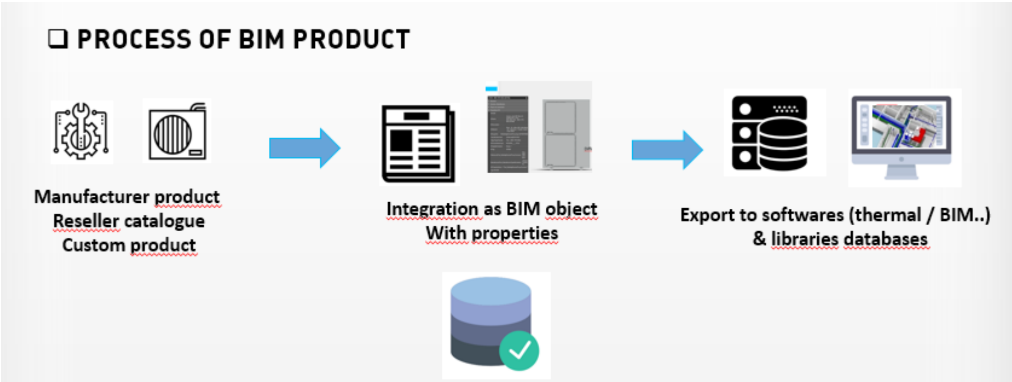


Figure 6. BIM process.

The impact of digital product information standards

The list the standards working groups covering the information in construction works and products is below (source AFNOR).

We have selected the relevant recent works in progress impacting our products under our CEN perimeter with BIM, objects, product data, exchange information and libraries. The BIM is defined as: "use of a shared digital representation of an asset to facilitate design, construction and operation processes to form a reliable basis for decisions".

The relevant themes

Out of these works, here are the most important subjects we consider creating a common framework for our HVAC-R product digital harmonization:

- **[Creation and governance of a data dictionary] prEN-ISO 23386: definition of properties waiting CEN public enquiry, which is the result of the initial works of AFNOR PPBIM works.** *For reminder, the process is as follows:* Activation of Work Item / elaboration of draft (8 to 12 months)/ CEN enquiry 12 weeks / analysis of comments (max 8 months) / formal vote 8 weeks (possibility of skipping) / final work 8 weeks / publication
- **[Structure of generic object in a dictionary] prEN-ISO 23387: product data templates**
- Normalization of Product Data Template (PDT) structure, within a standardized dictionary (prEN-ISO 23386) and relation to IFC structure (ISO 16739).
- **[Structure of product catalogue] link with ISO 16757 electronic catalogue products to see how the subject of catalogue values for instance is treated in IFC.**

Indeed, the first structure to define what is a property of an object/product and what are the attributes to fill for each property, and to what reference document it is related to and to what dictionaries. Thus a property will have an unique identifier and many attributes like in the table of **Figure 8**.

Figure 7a. ISO TC 59 standard (AFNOR source)

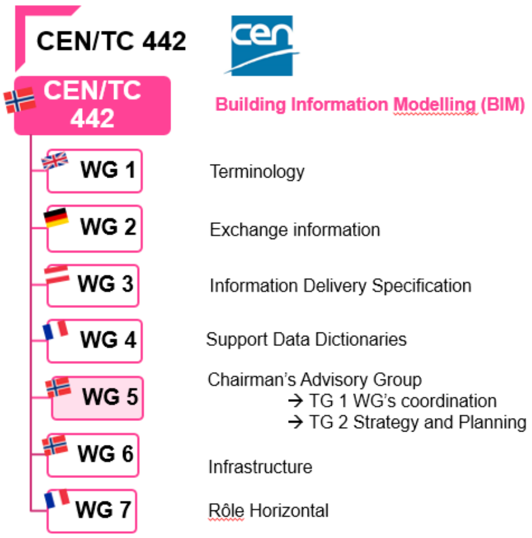


Figure 7b. CEN 442 standard (AFNOR source)

WGs (source AFNOR)	Standard & status
ISO /TC 59/SC 13 Organization of information about construction works	
WG 6 Framework for object-oriented information exchange	Link with CEN TC 442 WG4 dictionaries. **ISO 12006-3** Building construction -- Organization of information about construction works -- Part 3: Framework for object-oriented information. **ISO 16354:2013** Guidelines for knowledge libraries and object libraries.
WG 8 Building information models - Information delivery manual	Link with CEN TC 442 WG3. **ISO /NP 21597-1 & 2** Information container for Data Drop - Exchange specification - Part 1: Container Part 2: Dynamic semantics.
JWG 12 Development of building data related standards	WG2 **ISO 16739-1** Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries -- Part 1: Data schema using EXPRESS schema definitions.
WG 11 Product data for building services systems model	WG2 **prEN ISO 16757-1 & 2** Data structures for electronic Product catalogues for building services Part 1: Concepts, architecture and model & Geometry.
WG 13 Implementation of collaborative working over the asset lifecycle	WG3 **NWIP TR Guidance on how to implement EN ISO 19650-1 and -2 in Europe** **NP EN ISO 19650-3** Organization of information about construction works -- Information management using building information modelling -- Part 3: Operational phase of asset.
JWG 14 Joint ISO /TC 59/SC 13 - ISO /TC 211 WG: GIS-BIM interoperability	Link infrastructure.
CEN/TC 442 Building Information Modelling (BIM)	
WG 1 Strategy and Planning	
WG 2 Exchange information	PWI Exchange format for product data template.
WG 3 Information Delivery Specification	
WG 4 Support Data Dictionaries	2 TGs: properties definition & product data template. **prEN ISO 23386** Building information modelling and other digital processes used in construction -- Methodology to describe, author and maintain properties in interconnected dictionaries. **Pr EN ISO 23387** Product data templates, for products and systems used in construction works, stored in a data dictionary framework -- Part 1: General concepts, relations, and general structure of product data templates, and how to link the product data templates to Industry Foundation Classes (IFC). **PWI 442008** Product data templates, for products and systems used in construction works, stored in a data dictionary framework - Part 2: Specification of Product data templates based on harmonized technical specifications under the Construction Products Regulation (CPR), and how to link the product data templates to Industry Foundation Classes (IFC). prEN „Modelling and linking between semantic ontologies“: new TG.
WG 5/TG 2 Strategy and Planning	Harmonization between ISO / CEN / Building-smart International.
Other standards related	**ISO TC 184 STEP**

This standard project defines also the role of experts to validate the properties. **The European dictionary can now be defined with this process using the same semantic.**

BuildingSMART International proposes its Data Dictionary BsDD to help the users finding the properties dictionaries according to each country as a work-in-progress.

Other impacting new regulation & standards projects to follow:

- Smart CE marking: a Common Working Agreement CWA 17316 Smart CE marking for Construction products is implemented with a proposal of XML format
- asset life: the ISO 19 650 on asset will impact the digital process along the project and how the data will be monitored by the different stakeholders.

PPBIM - prEN23386		
group of properties (organized properties...)	**property (inherent or acquired feature of an item)**	**attribute (any data including description, interconnected dictionaries, type, list of values..)**
group of properties	property	guid - unique identifier
group of properties	property	statut
group of properties	property	date of creation
group of properties	property	date of activation
group of properties	property	date of last change
group of properties	property	date of revision
group of properties	property	date of version
group of properties	property	date of deactivaton
group of properties	property	version number
group of properties	property	revision number
group of properties	property	replaced by
group of properties	property	depreciation
group of properties	property	relation properties in inte
group of properties	property	creator language
group of properties	property	name language N
group of properties	property	definition language N
	property	description
	property	examples
	property	connected properties

Figure 8. Example properties.

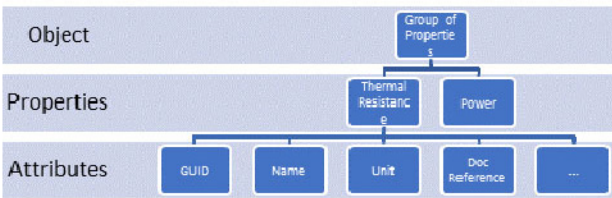


Figure 9. PPBIM Properties hierarchy.

Many points are being discussed with experts of CEN TC 442 WGs:

- How to deal with requests in IFC for catalogue products linked to other software like PIM?
- How to define product data templates?
- How to input the requirement, such as conditions of performance or regulations or project requirement, into a product using IFC. Example with "IfcConstraint" or complex properties on the way for Heat pump.
- How to define dynamic properties linked to other properties, and how to link the data together with the identifiers?
- How to qualify the source of the data in the product (declared, certified…) and the data which is modified after in a project by an author?
- How to control data using rule checking to check consistency, completeness etc… of data in IFC?

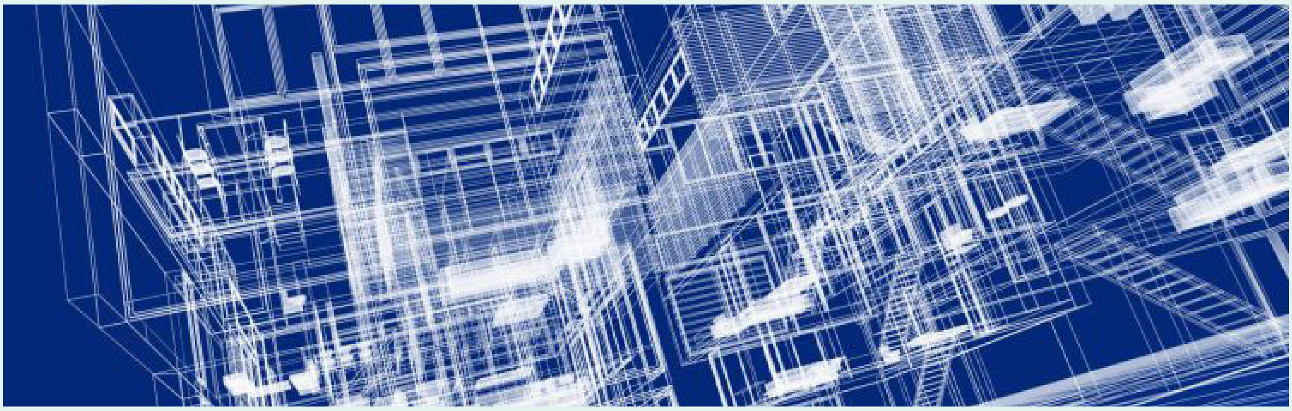
Conclusion

This overview is showing the CEN TC 442 topics to follow, and the BIM dedicated subjects in relation to our HVAC-R products digitalization and product data management.

Now the next step is to harmonize together a European dictionary of properties for our products to be able to exchange the information.

The BIM is forcing us to structure our framework quickly and push our HVAC-R dictionary as the first step towards the BIM standard. ■

About PRODBIM



In the context of the construction sector's ongoing digital transformation, the HVACR industry finds itself increasingly impacted by BIM (Building Information Modelling). Manufacturers are being challenged to comply with new BIM standards and working methods. The objective of PRODBIM is to support manufacturers in making effective use of the constantly evolving BIM market.

- PRODBIM is an initiative driven by Eurovent Service Company.

- PRODBIM will deliver a dedicated database online service to assist the set-up of your product data into a coherent PIM*, fully usable for BIM market and multi-countries codes.

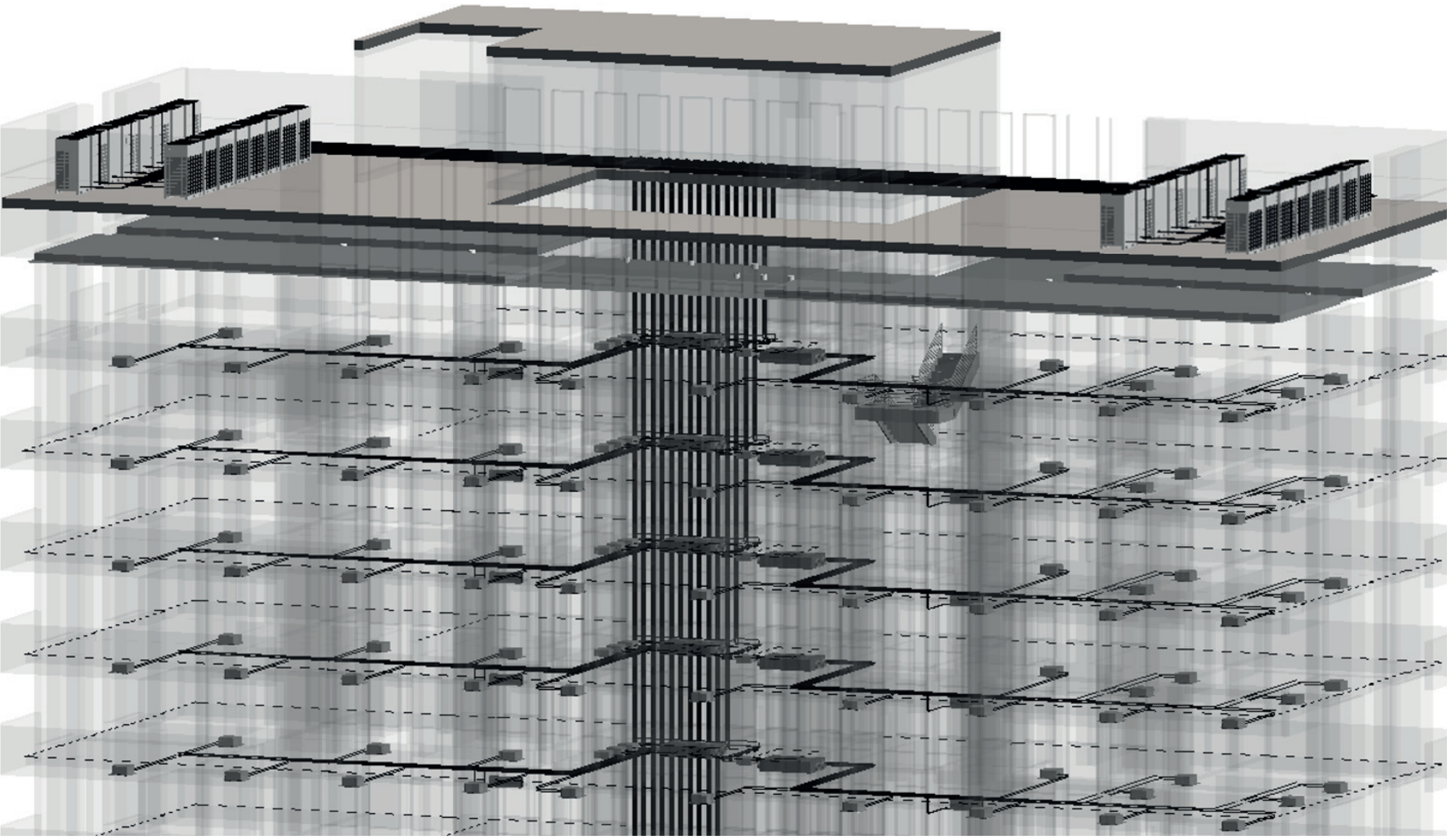
- PRODBIM is involved in the CEN TC 442 works and specifically in WG2 and WG4 on products, and member of BuildingSMART to follow the works.

- PRODBIM will deliver also the EPREL service for any manufacturers.

- **PRODBIM is also a Partner of REHVA.**

- PRODBIM is inviting interested HVACR manufacturers to participate in their Committees "BIM HVAC Product Database for Manufacturers" to harmonize their product properties.

For detailed information, please contact the author: Thibaud de Loynes, +33 6 30 14 45 50, t.deloynes@prod-bim.com.



LATS Revit

First VRF system selection and simulation for BIM

The pleasure in conceptual design comes from the effortlessness with which the equipment selection is done.

LG Electronics supports designers in their quest for efficient and friendly interface tools to simulate HVAC systems in building environment by providing a free of charge application, running under REVIT, called LATS REVIT.

The application is capable of reducing the time spent on designing complex variable refrigerant flow systems due to its integrated product familie, control accessories and automatic pipe size adjustment.

LATS REVIT simulates the cooling and heating capacities delivered to the building while guiding user to execute system design according to manufacturing specification.

A free tool that frees your time!

Faster
Smarter
Better

Innovation for a Better Life

LG Business Solutions

The Horizon 2020 BIM-SPEED project

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BIM-SPEED – which is an acronym for Harmonized Building Information Speedway for Energy-Efficient Renovation – is a newly funded project by the European Union's Horizon 2020 funding scheme. It is funded under the energy efficient buildings program with a project start in November 2018. In four years, the project will develop

- a cloud-based BIM platform that is open, affordable and user-friendly and
- a set of inter-operable BIM tools, existing and new ones, all connected through the BIM cloud platform.

Additionally, around these technical innovations, validated and standardized procedures for BIM-based activities throughout the whole renovation process will be developed.

The project starts from the premise that BIM for renovation and asset management of existing residential building stock is viable. This viability has already been proven in pilot projects by the BIM-SPEED consortium members and stakeholders, so that the BIM-SPEED project is set to get off to a "flying start". Housing corporations, research institutes, as well as, engineering and construction firms involved in BIM-SPEED have already successfully implemented Building Information Modelling (BIM) for energy-efficient renovation of residential buildings in Spain within a Smart Cities project led by housing corporations and contractors; in Germany by housing corporations in collaboration with BIM consultancy firms and universities; in France by housing corporations in relation with research institutes; and in Poland by the municipality of Warsaw together with a construction company.

Despite these initially successful projects, for a large-scale uptake across Europe, technological, economic and organizational bottlenecks remain so that the full potential of BIM can be leveraged. BIM-SPEED sets out to remove all these barriers by providing every stakeholder in the housing renovation market with holistic solutions during the four main stages of a renovation project:

1. Existing building data acquisition
2. Renovation design and engineering
3. Performance analysis
4. Execution of renovation works

Because the implementation of new innovative HVAC systems is one of the main tasks during the energetic renovation of buildings, BIM-SPEED will also develop new innovative HVAC related process solutions for each of the phases as described in the rest of this article.

Mapping existing HVAC systems

As a first step in every renovation project a sound understanding of the existing building needs to be developed. This is challenging for HVAC systems as much of the systems consist of non-visible parts that cannot be mapped by state-of-the-art survey methods, such as laser scans. BIM-SPEED will therefore develop advanced data fusion and machine learning methods for the optimal combination of non-destructive scan technologies (for example radio frequency, thermography, or radar) to reconstruct HVAC systems and installations. The methods will also fuse information fragments that are partially available in different existing documents such as as-built plans and specifications. As for most buildings it can be expected that the HVAC survey, despite all the use of latest technologies, will be incomplete, BIM-SPEED will develop an automated categorization scheme that can provide engineers a strong indication about the completeness of a specific reconstructed HVAC model.

Integrated renovation design and engineering

To support renovation design and engineering activities, BIM-SPEED will develop a BIM library of the most common HVAC equipment components that can be installed in the existing stock of residential buildings in the EU. An IT solution will additionally be provided to interface with the catalogues of renovation products/solutions for existing buildings provided by the major building companies, manufacturers and suppliers in the EU renovation market. The interfaces together with the library of parametric HVAC objects will allow seamless data exchange with existing design and engineering applications and databases and hence significantly improve the renovation design and engineering process. A specific focus of BIM-SPEED will be to ensure that the ontologies and interfaces provide all the information that is required for life-cycle analysis and costing assessments is available to renovation designers and engineers, so they can clearly understand the ramifications of implementing different HVAC solutions. All these solutions will be specifically designed to support renovation projects and will therefore contribute significantly to our ability to plan advanced HVAC solutions.

Performance analysis of HVAC renovation solutions

BIM-SPEED will also develop advanced methods to accurately evaluate the performance of different HVAC renovation solutions based on sophisticated whole building energy modeling (BEM) and simulation methods. Various simulations for building renovation modeling guidelines will be developed using relevant BEM tools, comprising energy, thermal load and HVAC performance analyses. BIM-SPEED will prioritize the use of BIM open standards over the usually proprietary input models of the commercial analysis tools. For this purpose, an automated input/output interface will be designed. This will allow for running multiple simulations of varying renovation solutions in search of the optimal energy performance that can account for different aspects of a building - not only including energy behavior, but also user comfort and life-cycle costs. Advanced simulation experimentation methods will also be established that will allow engineers to conduct large scale parametric studies of different possible renovation alternatives, understand the sensitivity of a building's energy performance on certain aspects of a building system, and to grasp the uncertainties inherent in any simulation result. Besides, possibilities for the automatic parametrization and calibration of simulation models with real-time data and weather forecast will be investigated to run dynamic simulations, extract results, and calculate key performance indicators, such as energy savings per year. In all aspects of simulation of building performances, the accurate simulation modeling of the HVAC systems will play an important role during the research and development work conducted on BIM-SPEED. The project will increase our possibilities to truly assess the effects of HVAC renovation solutions on building performance which will allow HVAC engineers to better size a building's new systems.

Execution of renovation works

BIM-SPEED will also provide new methods and processes to execute the renovation construction work. The project will develop a set of generative rules for deep renovation design that deal with building regulation compliance, for example, with regard to fire safety, renovation strategies, and the availability of building and HVAC product solutions at specific locations in Europe. The design rules will be defined by experienced building and HVAC designers, engineers, construction firms, technical consultants and asset managers. All design rules will be incorporated in a BIM-based

tool. This BIM-based tool will provide automated rule-based validators that can check candidate solutions with respect to their regulatory compliance and will discard all candidates that do not comply.

Additionally, different technical solutions will be developed for a cost-effective use of Virtual Reality (VR) and Augmented Reality (AR) to visualize the renovation process. The spatial visualization will allow building professionals and inhabitants to observe the renovation interventions within the building and in relation to the surroundings before the start of construction work. This will allow for planning all construction work upfront to enable a seamless installation of the chosen HVAC renovation products, but also to support workers on site with accurate installation instructions that are customized to the existing conditions of the building. The AR/VR solutions will be helpful to support the detailed engineering work that is required to integrate HVAC renovation products within existing buildings as it can support the engineering of connections and other interfaces. This task will also be concerned with developing an interface between the BIM platform and VR/AR platforms. ■

European Study on Heat Recovery in Non-residential Buildings

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The HR (heat recovery) is generally assessed very positively from a business and economic point of view.

In order to demonstrate this development, a study will evaluate around 5,000 design data elements. First, the designs are evaluated with the question of how the key efficiency characteristics of the HR have changed throughout the course of the years 2014 to 2017. Afterwards, all relevant design files are subjected to an economic efficiency calculation under defined conditions, in order to determine the potential for a multidimensional optimization. Furthermore, the impact of the EU 1253/2014 benchmarks from 2020 onwards will also be examined. The influence of the climate is thereby also taken into account by examining three European sites (North-South view). At the same time, the influence of the run time of the systems will be calculated.

Ultimately, the analyses will provide recommendations for the future design of the Eco-design regulation.

Field study on the development of heat recovery (HR)

Heat recovery systems have been used for years to reduce the required primary thermal energy demand in HVAC units and systems non-residential buildings.

Despite this positive development, the question arises more and more frequently as to whether these provisions of the Eco-design regulation EU 1253/2014[1] actually represent an optimum of the HR system in the microeconomic or national macroeconomic sense.

1 Commission Regulation (EU) No 1253/2014 from July 7, 2014 regarding the implementation of the Directive 2009/125/EC of the European Parliament and the Council regarding the requirements for the environmentally compatible design of ventilation systems. Published on 25.11.2014.

In order to answer this question, a total of approx. 4,800 air handling unit (AHU) designs from 2014 up to and including the first half of 2018 were evaluated according to economic aspects. These are actual designs that were carried out with TÜV-certified design software on the basis of specific tenders in a broad range of projects. Each device is therefore based on a real project with actual performance requirements that are in line with the market and therefore representative for the market of AHU´s used in non-residential buildings.

Each HVAC unit with HR was subjected to a quasi-dynamic economic efficiency calculation using a batch generator (software bot). Two usage cases were thereby investigated. On the one hand, a design with initial values, i. e. predefined basic conditions that are to apply equally to all designs, and on the other hand, a design with file values, i. e. the data that was already selected in the concrete design for the respective project during the original design.

When performing a consideration with initial values, the designs were also only evaluated for an identical location, while file values took into account the actual location that was already selected at that stage of the project.

Three locations were selected to take into account the general conditions (starting values) in Europe. In addition to Mannheim as a central European location, Lisbon was selected as the southern location and Helsinki as the northern location.

The annual differential costs were determined as the basis for the economic valuation. These result from the monetary recovery of heat in the winter, and the recovery of cold in summer. The expenses resulting from the electrical energy requirement, maintenance costs, debt service, etc. were deducted from this amount. The results for the recovered heat are shown in **Table 1**.

Table 1. Average thermal work of the examined designs.

		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	2,346		2,346	173,111	2,943	117,478	104	4.10	1.00
4865										
Middle	Mannheim	2,346		2,346	117,567	10,495	80,310	992	2.80	1.00
4829										
South	Lisbon	2,346		2,346	44,106	26,772	28,665	3,336	1.00	1.00
4698	units							11.6%		
		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	3,754		5,005	330,324	4,913	236,385	177	3.95	2.01
4875										
Middle	Mannheim	3,754	1,251	5,005	226,817	17,460	163,926	1,645	2.74	2.04
4822										
South	Lisbon	3,754	1,251	5,005	86,003	44,496	59,786	5,534	1.00	2.09
4774	units							9.3%		
		Day h	night h	total	Heat	colth	heat HR	colth HR	North-South	operating
		h/a	h/a	h/a	kWh	kWh	kWh	kWh	factor	time factor
North	Helsinki	4,380	4,380	8,760	510,922	6,221	389,513	230	3.74	3.32
4885										
Middle	Mannheim	4,380	4,380	8,760	359,659	22,274	277,637	2,077	2.67	3.46
4857										
South	Lisbon	4,380	4,380	8,760	139,423	57,753	104,018	7,058	1.00	3.63
4765	units							6.8%		
		Day h	night h	total	Heat	colth	heat HR	colth HR		
		h/a	h/a	h/a	kWh	kWh	kWh	kWh		
project values		3,972	1,902	5,712	300,596	17,462	219,780	1,865		
4885	units									

While in Lisbon heat is recovered on average W = 28,665 kWh/a for a run time of around L = 2,350 h/a, in Helsinki this is W = 117,478 kWh/a for the same run time (see **Figure 1**).

If the plants examined are operated around the clock, the HR in Lisbon W = 104,018 kWh/a and in Helsinki W = 389,513 kWh/a. This corresponds to about a factor of four between northern and southern Europe. In Mannheim, around 2.7 times the heat could be recovered compared to the south. It also becomes apparent that approximately 3.5 times as much energy can be recovered in a 24-hour operation as in the 9-hour operation (L = 2,350 h/a).

The average temperature transfer rate of all designs was Φ = 71.9% with a standard deviation of s = 5.8 percentage points during the period under study.

By contrast, the recovery of sensitive cold is very low (see **Figure 2**) and even in Lisbon there is a maximum of 11.6% heat energy (see **Figure 1**). In Helsinki, the share of cold recovery is irrelevant, as it only accounts for 0.1% of the heat energy.

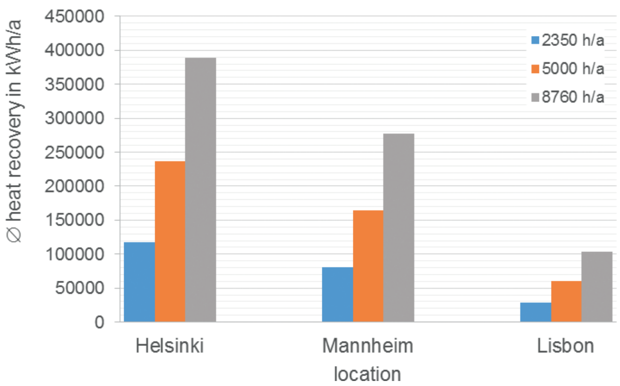

Figure 1. Average heat recovery of the plants in kWh/a

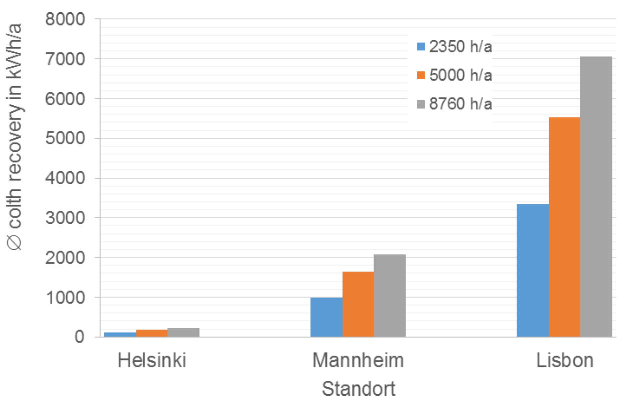

Figure 2. Average cold recovery of the plants in kWh/a.

Based on the actual project data (mostly in Germany), the average run time of the plants was L = 5,712 h/a with an average recovery of W = 219,780 kWh/a.

If the monetary effect of the HR is calculated, the results are shown in **Table 2**. This was calculated with a price of 0.08 €/kWh for heat, an electricity price of 0.17 €/kWh, and a price of 0.05 €/kWh for cooling energy. An imputed interest rate of 3%/a was applied. The rate of price increase was 2%/a. The useful life of the HR was selected with 15 years. The utilisation of the HR unit during daytime hours is assumed to be 100% of the target air volume, and at night hours 50%. The investment costs of the HR systems in the study are averaged at I = €25,100.

In a 9-hour operation (around L = 2,350 h/a), the plants examined in Lisbon would generate an average loss of K = −1,737 €/a at an efficiency of 71.9%. Overall, 93.7% of all investments in Southern Europe would be uneconomical (negative differential costs per year), while a profit of K = 5,233 €/a would be generated in Northern Europe for the same term. In Helsinki, therefore, only 2.1% of specific installations would generate project-specific losses.

In the 24-hour operation, an average profit of K = 2,741 €/a would even be generated in Lisbon. However, even with this run time, 7.4% of the examined plants would still generate a loss. In Helsinki, however, it would be possible to generate a profit of K = 25,171 €/a with the same investments (see also **Figure 3**). Under these conditions, none of the plants examined would be uneconomical at this location.

If all plants were economically optimized at a constant design speed, a higher profit would be generated, which could avoid a loss on average for all plants.

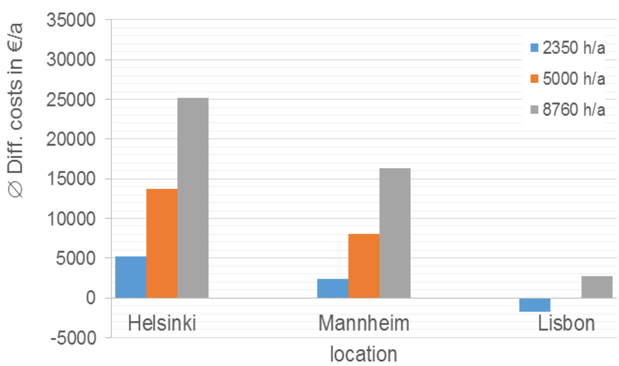

Figure 3. Annual differential costs under design conditions.

However, the systems with average transmission degrees from Φ = 33.4% in Lisbon to Φ = 65.2% in Helsinki would then have to be produced, i. e. with significantly lower transmission rates than the actual, resulting average and undifferentiated Φ = 71.9% of the systems investigated in this field study. In Mannheim, the optimum transmission degree under these conditions would be Φ = 58.3%.

With a run time of L = 5,000 h/a, transmission degrees of Φ = 47.4% in Lisbon and Φ = 72.3% in Helsinki would be required. Mannheim then requires a transmission degree of Φ = 67.2% at unchanged flow velocity.

Even during the 24-hour operation (L = 8,760 h/a), transmission degrees of Φ = 56.9% (Lisbon) and Φ = 76.8% (Helsinki), as well as Φ = 72.8% (Mannheim) would make sense. A 2.8% higher profit could be generated in Helsinki, while a 43.6% higher profit could be achieved in Lisbon.

If a multidimensional optimization is carried out at a flow velocity of about w = 1 m/s, significantly higher gains could be achieved (see **Figure 4**). For a 9-hour operation in Mannheim, for example, the annual differential costs could be increased to € 4,097/a (+ 76.2%) with an average of K = € 2,325/a.

A significant increase in yields would also be possible in 24-hour operation, which could be +22.3% in Helsinki (K = 25,171 €/a to K = 30,774 €/a) and +119.1% in Lisbon (K = 2,741 €/a to K = 6,005 €/a) (see **Table 2**).

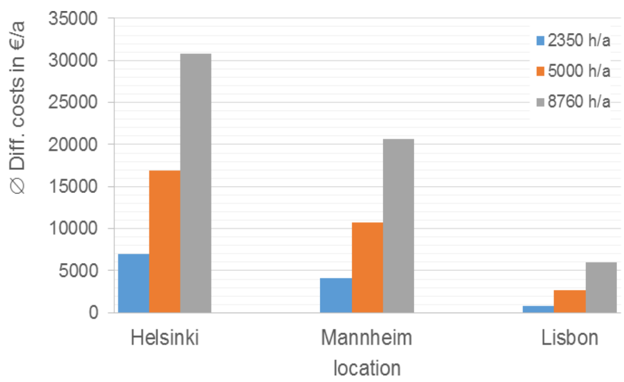

Figure 4. Annual differential costs after 3D optimization.

Table 2. Monetary results (differential costs average values) of the economic efficiency calculation.

		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
2.350 h/a		€/a	€/a	%	€/a	%	€/a	%	€/a		m/s
North	Helsinki	5,233	5,699	65.2	464	8.9%	6,944	71.0	1,711	32.7%	1.01
			s =	7.96			s =	9.18			0.09
Middle	Mannheim	2,325	3,165	58.3	832	35.8%	4,097	65.3	1,772	76.2%	1.01
			s =	9.27			s =	10.64			0.09
South	Lisbon	-1,737	447	33.4	2,130	-122.6%	773	44.7	2,510	-144.5%	1.03
			s =	14.30			s =	14.60		s =	0.12
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
5.000 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
North	Helsinki	13,676	13,955	72.3	276	2.0%	16,945	78.7	3,269	23.9%	1.00
			s =	5.98			s =	6.91			0.07
Middle	Mannheim	8,014	8,401	67.2	387	4.8%	10,762	74.8	2,748	34.3%	0.99
			s =	6.76			s =	7.98			0.06
South	Lisbon	-135	1,628	47.4	1,745	-1292.5%	2,725	59.7	2,860	-2118.2%	0.99
			s =	10.07			s =	11.85		s =	0.06
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
8.760 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
North	Helsinki	25,171	25,865	76.8	693	2.8%	30,774	82.8	5,603	22.3%	1.01
			s =	5.02			s =	5.84			0.07
Middle	Mannheim	16,326	16,604	72.8	277	1.7%	20,616	79.9	4,290	26.3%	0.99
			s =	5.57			s =	6.53			0.06
South	Lisbon	2,741	3,949	56.9	1,196	43.6%	6,005	68.3	3,264	119.1%	0.98
			s =	8.37			s =	9.77		s =	0.04
		Diff. Costs	1D Opt.	HRE	Delta 1D	Delta 1D	3D Opt.	HRE	Delta 3D	Delta 3D	3D w
5.712 h/a		€/a	€/a	%	€/a		€/a	%	€/a		m/s
project values		16,255	16,902	71.8	636	3.9%	19,873	77.4	3,617	22.3%	1.02
			s =	8.42			s =	8.80		s =	0.09

However, even in this case, the optimal transmission degree is not identical in the different locations. While in Lisbon max. Φ = 68.3% makes sense, in Helsinki this is Φ = 82.8%. In Mannheim, the maximum transmission degree under these conditions is Φ = 79.9%. In the 9-hour operation, the maximum meaningful transmission degrees are reduced to a maximum of Φ = 71.0% in Helsinki, Φ = 65.3% in Mannheim and Φ = 44.7% in Lisbon. However, all transmission degrees can only be used sensibly if the flow velocity for design is around w = 1 m/s in order to minimize pressure losses.

In Germany, in contrast to the chosen framework conditions, +22.3% higher yield could be achieved in accordance with the project-specific, individual values (cf. **Table 2** bottom line). The higher value is due to the fact that higher specific energy prices were expected in the specific projects.

Reference points

If the EU1253/2014 reference values, which are to enter into force from 2020 as part of the revision of the Ecodesign regulation are applied today, the result will be as follows (see **Table 3** and **Table 4**).

On average, the HR would have to be twice as large in its transmission units as it has been in recent years.

In Helsinki, a 9-hour operation could no longer generate a profit of K = 5,233 €/a compared to the situation in recent years, with a yield of only of K = 2,609 €/a (see **Table 4**).

In Lisbon, instead of the loss of K = –1,797 €/a already incurred today, a significantly higher loss of K = –5,566 €/a would be the result. And in Mannheim a loss of K = –789 €/a would result instead of an average profit of K = 2,325 €/a. Even with a 24-hour operation (L = 8,760 h/a), the plants examined in Lisbon would cause an average loss of K = –1,905 €/a.

Figure 5. Annual differential costs under various conditions for Helsinki.

Even under the current conditions, an average profit of K = 2,741 €/a would still be possible in Lisbon. By comparison, the same investments in Helsinki would generate an average profit of K = 25,171 €/a (in Mannheim K = 16,326 €/a).

Figure 5 and **Figure 6** also show the annual savings for the Helsinki and Lisbon locations with different run times. Even at an optimal flow velocity of about w = 1 m/s, the reference values of the EU1253/2014 would cause lower yields. Although the average transmission degrees would be between Φ = 83% and Φ = 84%, all yields would be lower than in the multi-dimensionally calculated optimum. **Figure 7** shows the corresponding result for Mannheim.

Even in Helsinki, 24-hour operation would reduce the yields from K = 30,744 €/a to K = 30,505 €/a, i.e. by –0.9%. In Lisbon, on the other hand, a 9-hour operation (L = 2,350 h/a) would turn the remaining small profit of K = 773 €/a into a significant loss of K = –2,877 €/a.

Table 3. Necessary change of the heat exchanger index Number of transfer units (NTU) under reference conditions.

		NTU actual	NTU target	NTU Factor target / actual
North	Helsinki	2.69	5.08	2.04
	s =	0.90	0.80	0.79
Middle	Mannheim	2.69	5.08	2.04
	s =	0.90	0.80	0.79
South	Lisbon	2.69	5.09	2.05
	s =	0.90	0.80	0.81

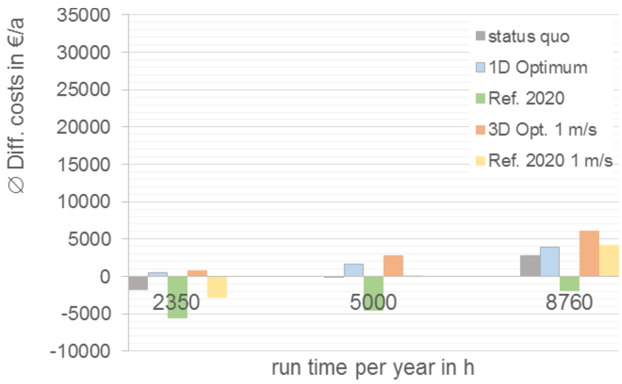

Figure 6. Annual differential costs for Lisbon under different conditions.

Table 4. Monetary results of the economic efficiency calculation under reference conditions.

	run time	Diff. costs K Actual	Diff. costs K Opt.	Diff. costs K Ref. 2020	Diff. costs K 3D Opt.	Diff. costs K Ref. 2020 (1 m/s)
	h/a	€/a	€/a	€/a	€/a	€/a
Helsinki	2,350	5,233	5,699	2,609	6,944	5,399
North	5,000	13,676	13,955	11,476	16,945	16,230
	8,760	25,171	25,865	24,186	30,774	30,505
Mannheim	2,350	2,325	3,165	-789	4,097	1,984
Middle	5,000	8,014	8,401	4,926	10,762	9,612
	8,760	16,326	16,604	13,878	20,616	20,041
Lisbon	2,350	-1,737	447	-5,566	773	-2,827
South	5,000	-135	1,628	-4,537	2,725	87
	8,760	2,741	3,949	-1,905	6,005	4,106

Table 5. Possible transmission degrees of the HR and their average annual differential costs.

		3D-Optimum	Ø Diff.- costs	ΔP average
		%	€/a	Pa
Helsinki	2,350 h/a	71	6,944	61
North	5,000 h/a	79	16,945	91
	8,760 h/a	83	30,774	119
		%	€/a	Pa
Mannheim	2,350 h/a	65	4,097	47
Middle	5,000 h/a	75	10,762	71
	8,760 h/a	80	20,616	96
		%	€/a	Pa
Lisbon	2,350 h/a	45	773	21
South	5,000 h/a	60	2,725	35
	8,760 h/a	68	6,005	51

Figure 7. Annual differential costs for Mannheim under various conditions.

Evaluation

It should be noted that the HR has successfully established itself in Europe. However, if the EU 1253/2014 reference values are actually converted into applicable law as of 2020, the recovered heat output will increase by around 15%, but the amount of equipment required will increase by a factor of around 2.

This development is not economic, as the average yields of the HR will fall across Europe. This has been clearly demonstrated by the field study at the individual case level at around 4,800 plants examined.

Yields will fall significantly in all cases. In the quintessence of the findings, the application of the reference values in Europe from 2020 will not make any investment in Europe more economical than it is today.

It is to be hoped that the European Commission will also recognise and correct this design error in the regulation. It makes sense that the revision of the regulation must at least take into account both the location of installation of the HR and its run time.

If the results of the field study are reduced to the transmission degree, the following values could be useful for minimum transmission rates and maximum pressure losses at the HR (see **Table 5**).

The air velocity in the device should then be about w = 1 m/s. Lower air speeds are hardly sensible any more, as the systems should also to operate at partial load. At an air velocity of w = 1 m/s a partial load operation up to about w = 0.4 m/s would be possible. ■

LIST OF ABBREVIATIONS

AHU	Air handling unit
ΔP	Differential pressure loss [Pa]
I	Investments [€]
K	annual differential costs [€/a]
L	Runtime [h/a]
NTU	Number of Transfer units [./.]
Φ	Temperature transfer coefficient or heat recovery efficiency [%]
HR	Heat recovery
s	Standard deviation
w	Flow velocity at the narrowest cross section in [m/s]
W	Thermal energy [kWh/a]

Improving control quality and reducing pump energy consumption of AHU

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Hydronic systems supply air handling units with thermal energy. In these systems, nowadays typically the valves take the control task, whereby pumps operate on their design point settings. This causes high electric energy consumption and poor control quality in part load conditions. In order to address these aspects, we developed and evaluated new control concepts.

Keywords: AHU, Control, Pump, Energy Savings, Hydronic

Introduction and state of the art

In order to have the air conditioned in terms of heating, cooling, dehumidification, humidification for the use in buildings, AHUs use thermal energy as well as electric energy. In most cases, hydronic networks supply the air with this thermal energy using water to air heat exchangers (e.g. cooler, preheater). These hydronic networks consist of pumps, pipes and valves, which are dimensioned for the full load case. Operation points, close to the full load case are rare in real operation. For this reason, the systems usually operate in inefficient part load mode [1].

Depending on the requirements, we can arrange single heat exchangers, valves and pipes in a different hydronic configuration, which are called hydronic standard circuits (**Figure 1**) [2]. For instance, the mixing circuit and the injection circuit are well qualified for a uniform air temperature distribution downstream of the heat exchanger. The injection and the diverting circuit guarantee low dead times in case of suddenly appearing thermal loads (e.g. for frost protection). These circuits either vary the water volume flow at a constant supply temperature (systems 1 and 4 in **Figure 1**) or the water inlet temperature in the heat exchanger with a constant

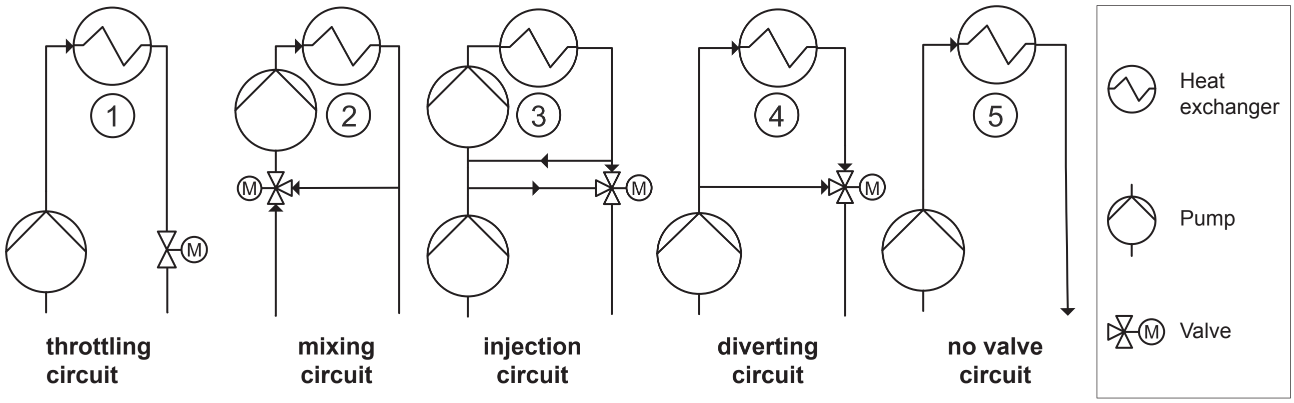

Figure 1. Hydronic standard control systems.

volume flow (systems 2 and 3 in **Figure 1**). Today, the valve lifts are the only actuating variables in the circuits, controlling the control variable (temperature, humidity, enthalpy) of the air downstream the heat exchanger. In this case, the pump runs at its maximum speed (older pumps) or varies its pressure depending on the volume flow internally (newer pumps) resulting in unnecessarily high pump energy consumption. Typical valves for building technology have low adjustment speeds (1-2 minutes for full valve lift), which we need to consider in operation and control parameter settings of the circuits [2].

For good control quality in part load cases, valves are dimensioned via valve authority criteria of values between 0.3 and 0.5 [2]. The valve authority is defined as the pressure loss over the fully open valve divided by the pressure loss of the closed valve at design point conditions. This leads to pressure losses over fully open valves being as high as the entire pressure loss of the rest of the hydronic circuit, including the heat exchanger. However, today even systems with high valve authorities can have poor control quality. One reason for this is the use of demand-oriented ventilation in AHU, which causes high ratios of design and minimum thermal power of more than 35 [2], as well as high nonlinearities in the controlled systems. Therefore, those systems are very hard to control with constant PID parameters for all load situations. In real AHU systems, this can lead to permanent oscillations. To avoid permanent oscillations, slow PID parameters can be used, so it can take hours to reach the temperature set value.

In addition, the effects of those standard hydronic concepts can even decrease efficiencies of heat sources (e.g. condensing boiler) or destroy the stratification of thermal storages by high return temperatures, as happened on one occasion in our institutes' main building, for instance. In our own facilities, which we also use for experimental purposes, most heating coils of AHUs including some reheaters are equipped with injection circuits. However, reheaters do not need injection circuits, as frost protection is not required. Adding the design volume flows of all injection circuits, we have a water volume flow of more than 23 m^3/h in our facilities, even when there is nearly no heat demand. To minimize the water volume flow rates, we installed balancing valves in most of the lower bypasses of the injection circuits. Nonetheless, for changes like these we have to consider negative effects on valve authority, which can decrease controllability of the systems again.

One reason for the inefficient state of the art of the operation of hydronic systems is the integration of constant speed pumps in the past, later substituted by pumps with a small ratio of maximum to minimum pump speed (frequency ratio) of two, for instance. However, due to latest developments in pump industry, pumps with frequency ratios up to 10 and a change of the pump speed within milliseconds are available, which enable them to become an important part in new AHU control concepts.

New Concepts

In order to achieve pump energy savings and improve control quality, we analysed the current control concepts for possible improvements taking into account the regulating variables "pump speed" and "valve lift". In this paper, we will focus on three concepts, which mainly address potential electric energy savings of pumps:

1. Throttling circuit: First pump then valve control (1 in **Figure 1**)

2. No valve: Pump only control (5 in **Figure 1**)

3. Mixing circuit: Constant mixing ratio for lower loads with pump control (2 in **Figure 1**)

All concepts work on two different modes depending on the actual relative thermal load.

The first concept uses the pump to control the temperature for higher loads with fully open valve until the minimum pump speed is reached in smaller loads [2]. Then the valve takes the control task, whereby the pump operates at minimum speed.

The second concept uses no valve and only the pump for control purposes, which results in a maximum reduction of pump energy. As we do not need a valve, we have a decrease of up to 50% of hydronic resistance in the circuit. Due to the reduced resistance, a smaller pump with less minimum power can be used. If the minimum pump speed is too high in low part load condition, the pump changes to pulsing operation, i.e. it switches on and off in certain intervals. This concept is only appropriate for well-designed hydronic systems, where no other pumps push in this local circuit and the volume flow becomes zero if the pump is turned off.

The third concept is suitable for heat exchangers, which have a high ratio of design to minimal thermal power. Here, in part load cases the 3-way-valve stays at a constant medium mixing position (e.g. 65% open) and the pump takes the control part. For higher loads, as soon as the pump speed exceeds 80%, the valve begins to open slowly until it reaches the 100% open position.

Evaluation of concepts

For the evaluation of the new concepts, we built a testing facility (see [1]) and performed dynamic simulations with Modelica (models will be available open source on https://github.com/RWTH-EBC/AixLib). To proof the transferability of the concepts, we are currently performing a field test on two further AHUs.

Although we used the testing facility to demonstrate pump energy savings of up to 86% for the preheater in [1], its main task is to demonstrate the control quality of standard and newly developed concepts. In the testing facility we focus mainly on the components cooler and preheater (for technical data see **Table 1**), which can be used for adiabatic humidification. Therefore, the preheater has to reach high temperature differences of more than 45 K during full load.

In order to evaluate the control quality in different load situations, we performed defined test cycles (see **Figure 2** and **3**), in which we varied the air volume flow from 3,000 m³/h (left, design value) to 2,000 m³/h (middle) and finally to 1,000 m³/h (right). Depending on the component, we varied the set temperature (preheater) or the entrance temperature (cooler) between 15°C and 35°C in 5 K steps hourly, whereby the control parameters stayed constant. We used ambient air for the entrance conditions, so results should be compared with care, as the entry conditions are not perfectly the same. We determined the PID control parameters for the standard concept applying controller tuning methods like Ziegler and Nichols, which resulted in poor control qualities. For this reason, we used control parameters from experience from diverse test measurements with a good control quality. Determining good control parameters for the new concepts took much less effort compared to the standard control concepts.

For the first concept, which we tested for the preheater, the control quality does not change significantly compared to the standard case [1]. We demonstrated the second concept with the cooler, cooling down the entering air (orange) to a set temperature of 13°C (red: set value, blue: exit value) with the pump (**Figure 2**). As there was nearly no dehumidification, which causes more than 44% of the coolers design power, the pump operates mostly in on-off (pulsing) mode or is close to the minimum pump power (green) of about 75 W, which is less than 10% of the design power (1,100 W). Only at the highest entrance temperatures at 3,000 m³/h and 2,000 m³/h the pump operates at a speed of up to 1050 1/min. In these cases, we obtain a good control quality, with small deviations on the scale of measurement accuracy. The pulsing pump operation worked acceptable at 3,000 m³/h (deviation < 0.5 K) and caused high deviation of more than 1.5 K at 1,000 m³/h. Those deviations are not acceptable and cause an increase of cooling energy, which overcompensates pump energy savings. The reason for this effect is that the time constants of the controlled system

Table 1. Technical design data of AHU heat exchanger systems.

Component	Humidity air in g/kg	Temp. air in°C	Thermal power in kW	Pump speed min/max in 1/min	Pump power min/max in W	Hydr. temp. in°C
Preheater	0/0	–15/42	57.7	800/3700	5/120	70/50
Cooler	23.8/13.3	45/20	53.4	750/2900	75/1100	6/12
Reheater	0/0	–13/9	22.3	500/4800	2/60	70/50

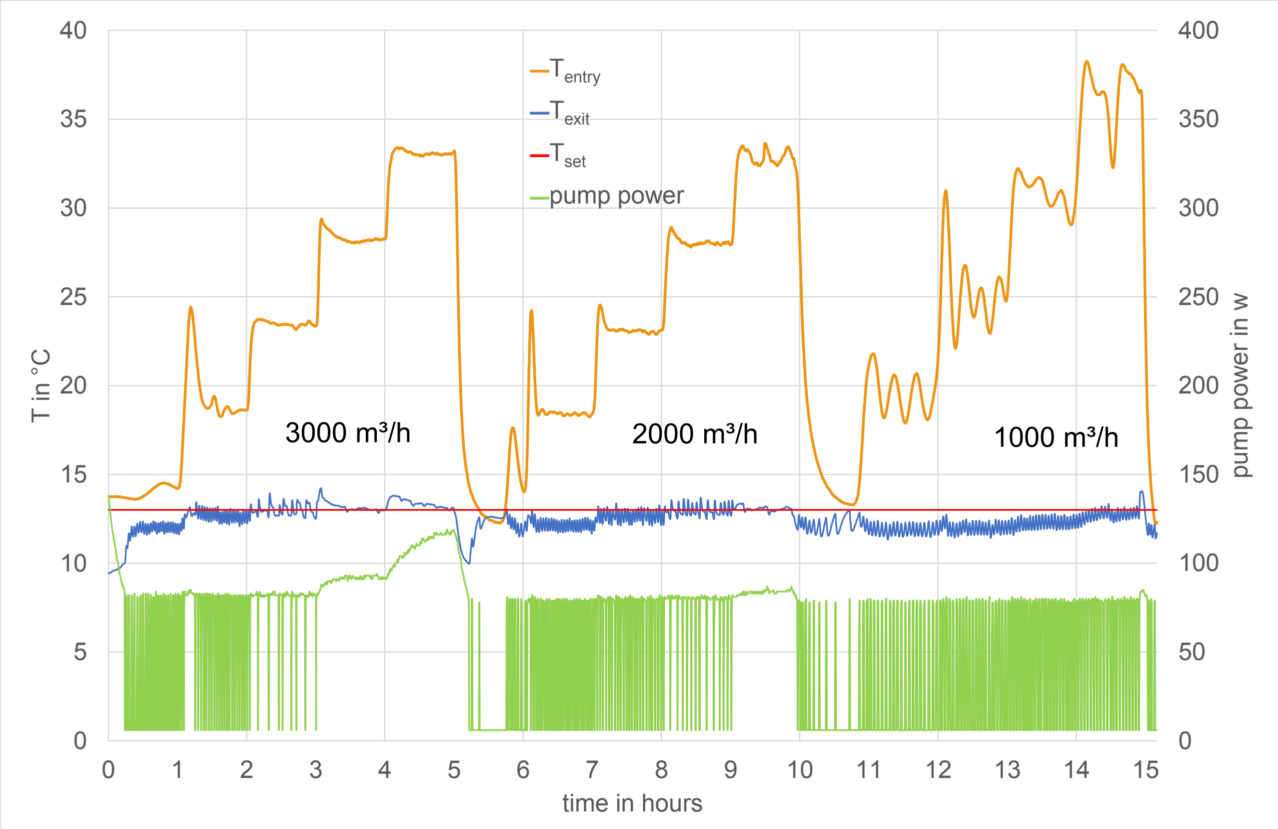

Figure 2. Pump only control for the cooler.

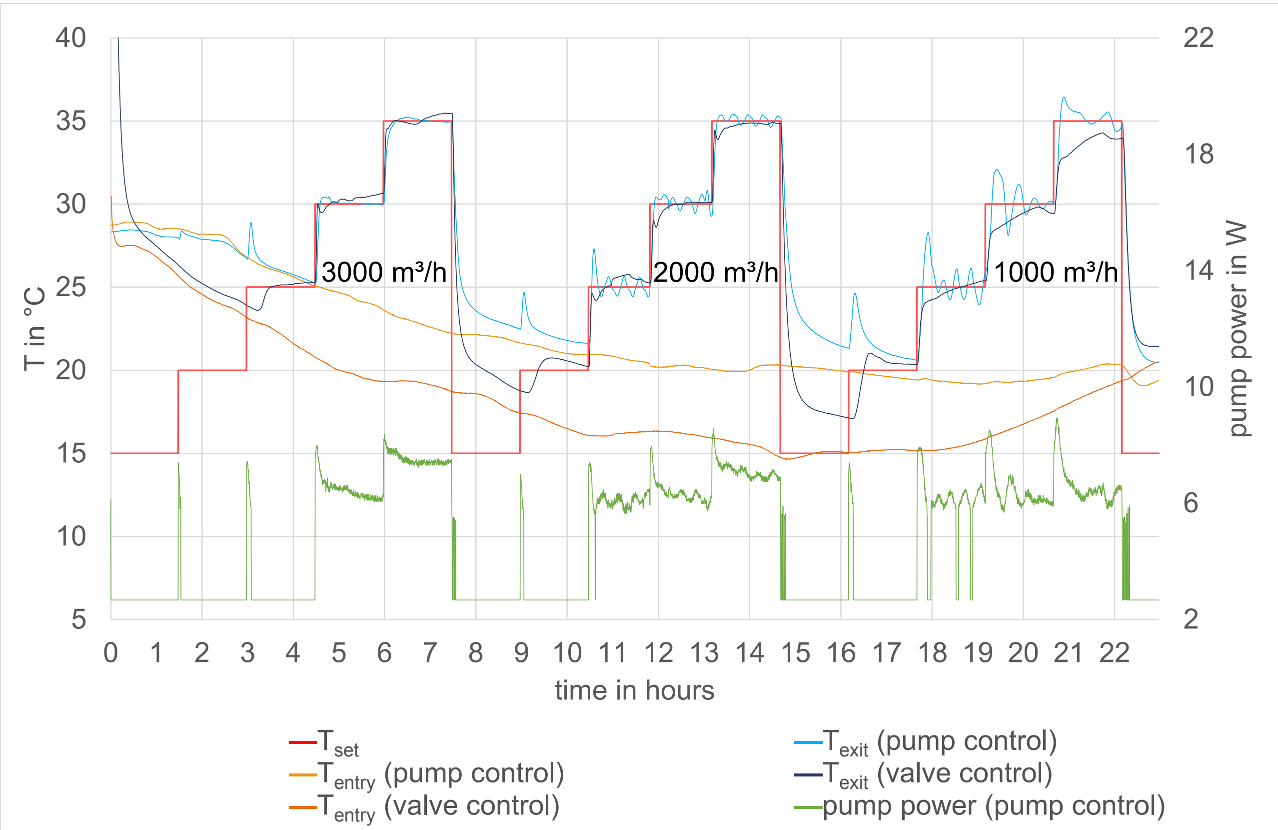

Figure 3. Comparison of valve and pump control (concept 3) for mixing circuit.

vary with the air volume flow, whereby the interval of pulsing pump operation stays constant.

The exit temperatures of the preheater for the third concept (light blue) in comparison to the standard mixing circuit control (blue) illustrates in **Figure 3**. At 3,000 m³/h, the third concept achieves the new set value (red) faster and more precisely compared to the standard concept. At lower air volume flow rates there are small overshoots and oscillations of less than 0.5 K for 2,000 m³/h or around 1 K for 25°C at 1,000 m³/h. The highest oscillations are caused by pulsing operation of the pump, as observed in the electric power trend of the pump (green). The maximum power for this test is 9 W and the lowest power 2.5 W (pump off). This corresponds with a reduction of 96% pump energy in this part load test cycle compared to 120 W in the standard mixing circuit.

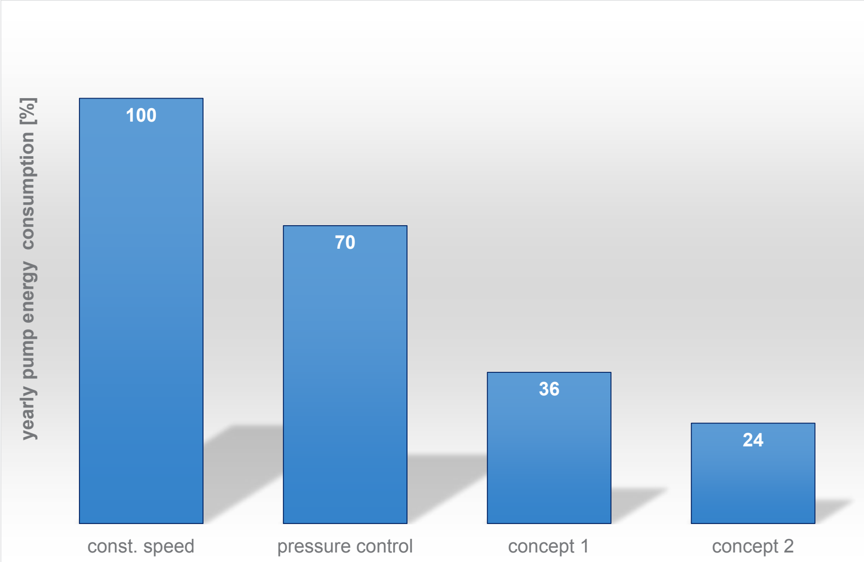

Figure 4. Comparison of pump energy consumption for different concepts.

For the energetic evaluation on yearly base, we used dynamic simulations with German weather data [3] and focused on the cooler of our testing AHU with a constant air volume flow of 3,000 m³/h. As illustrated in **Figure 3**, the throttling circuit with constant speed pump consumes 1,589 kWh/a, followed by the internally pressure-controlled pump with savings of 30%. Compared to this, our first concept could save around 64% and the second concept with a smaller pump 76% (1,229 kWh) of pump energy. Using a standard mixing circuit, we have the highest electric consumption of around 2,500 kWh in around 2,050 annual operation hours per year, which is nearly the double of the constant speed pump throttling circuit concept.

Conclusion and Outlook

With our study we have pointed out problems of the state of the art of hydronic control concepts and demonstrated new control concepts for the hydronic circuits of AHUs, which save up to 76% of pump energy or increase control quality in our test cases. The shown simulated energy savings can even increase, as they strongly depend on profiles of demand-oriented ventilation and weather conditions. The control quality further depends on the dimensioning and operation of the AHU system. As the pumps in the analysed hydronic systems have medium modulation ratios of 4.6 and 3.7, we could even increase the control quality by preventing pulsing operation with pumps of higher ratios like the reheaters pump (with a ratio of 10). However, we have to consider the certain negative effects of poor control quality, which can even overcompensate pump energy savings.

In order to improve the control quality, we are going to publish further developed concepts, which focus particularly on this topic. This includes new concepts for run around coils. ■

Acknowledgements

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References

[1] Teichmann, J. et. al: Reducing energy consumption of air handling units by optimized pump control. Roomvent & Ventilation 2018, Helsinki; 06/2018.

[2] Roos, H.: Hydraulik der Warmwasserheizung. Oldenbourg Industrieverlag, pp 71, 138-1, 2002.

[3] TRY (2010), German Meteorological Service (Deutscher Wetterdienst): Dataset 2010, region 12.

Air-to-Water Heat Pump in Heating System

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The subject of the paper is a capability assessment of heat pumps both in the in a classical design with an on / off power control and those with a variable speed control of the compressor to meet variable demands of the heating system during the heating period.

Keywords: heat pump, heating system, heating factor, heating, European reference heating period

The heat pump and the heating system (hereinafter referred to as the HP and the HS) are two separate units with different characteristics. The lower the outside air temperature, the higher the heating system demands on the heat, both on its quantity and the temperature level. For a long time, only heat pumps with constant compressor speed depended on the frequency of the electrical grid 50 or 60 Hz were available, where the HP regulation according to the needs of the heating system was solved by the jumping system on / off. The shortage of heating capacity below the bivalent temperature is covered by an additional heat source, very often an electric boiler. Excess heat has to be accumulated in heating water, whose temperature than rises above the required heating system inlet temperature.

Comparison of heat pumps with constant and variable speeds

An example of the capacity and temperature relationship in the HS during the heating period is shown in the graphs of **Figures 1–4**. The graphs are processed for the average climate conditions according to EN 14825 (minimal ambient temperature –10°C, maximal 16°C), objects with two nominal heat loss of 20 kW and 30 kW, two heating systems represented by a low-temperature one of 35/30°C and a high-temperature one of 55/47°C and the HP with refrigerant R410A. The figures on the left refer to the HP with the constant speed compressor ZH15K1P-TFM of displacement of 11.7 m³/h (heating capacity 16.8 kW at A2/W35), the figures on the right refer to the variable speed compressor ZPV0631E-4E9 of displacement of 11.0 m³/h (at 50 Hz). The monitored quantities are indicated in the figures as follows:

▬	Qloss	thermal loss of the building in kW
◆	QHP	heating capacity of the HP in kW
▬	QB	heating output of electric boiler in kW
▬	THSin	water temperature at the inlet to the HS
▬	THSout	water temperature at the HS outlet
▲	THPin	water temperature at the inlet to the HP
▪	THPout	water temperature at the HP outlet

If a constant speed HP with the previous mentioned compressor size is used in an object with a nominal heat loss of 20 kW and a low-temperature heating system of 35/30°C (**Figure 1**, left), it results a bivalent operation (bivalent parallel) with the balance point determined by capacity. The balance point temperature is about –3°C and besides the HP, a bivalent heat source with a capacity of up to about 7.5 kW for ambient temperatures of –10°C is required.

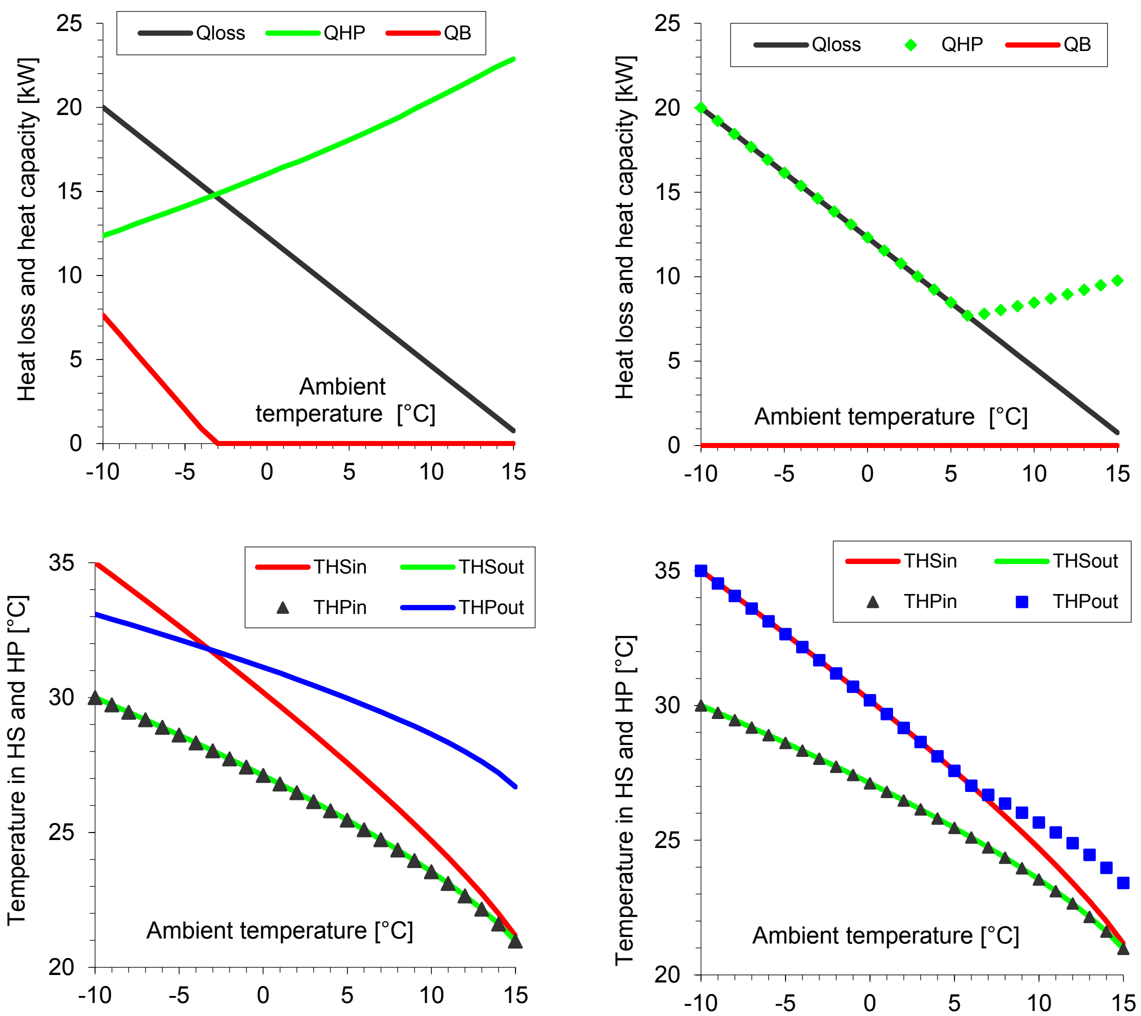

Figure 1. Low-temperature heating system 35/30°C with a heat pump and nominal building heat loss of 20 kW (constant speed compressor on the left, variable speed compressor on the right).

If a variable speed compressor is used, it operates in the frequency range of 20 Hz to 85 Hz and, therefore, still has a capacity reserve, since the maximum frequency is 120 Hz. It can be seen that the temperature of the water leaving the HP exceeds the required inlet temperature to the HS only at ambient temperatures over 6°C because the compressor cannot operate at a frequency below 20 Hz to reduce the heating capacity to the desired HS value. The system can be rated as monovalent.

If the high-temperature heating system 55/47°C was used in this object, the operating conditions would correspond to the state shown in **Figure 2**. A significant change will occur in the HS with an HP with a variable speed generator, where the system converts from monovalent into bivalent – partially parallel. With outdoor air temperatures below −5°C, the heat pump still has sufficient heating capacity (the compressor frequency is only about 59 Hz), but it cannot heat the water to the desired HS temperature because the condensing temperature would go beyond the compressor's operating limits. In order not to exceed the maximum allowable condensing temperature, the compressor speed is gradually reduced at outdoor temperatures of approx. −5°C to −9°C, but the compressor's operating range decreases significantly, especially at speed below 40 Hz (see **Figure 5**), so at the ambient temperature below −9°C, the compressor should be switched off. This is reflected, among other things, by the need to dimension a bivalent heat source to the full nominal object's heat loss.

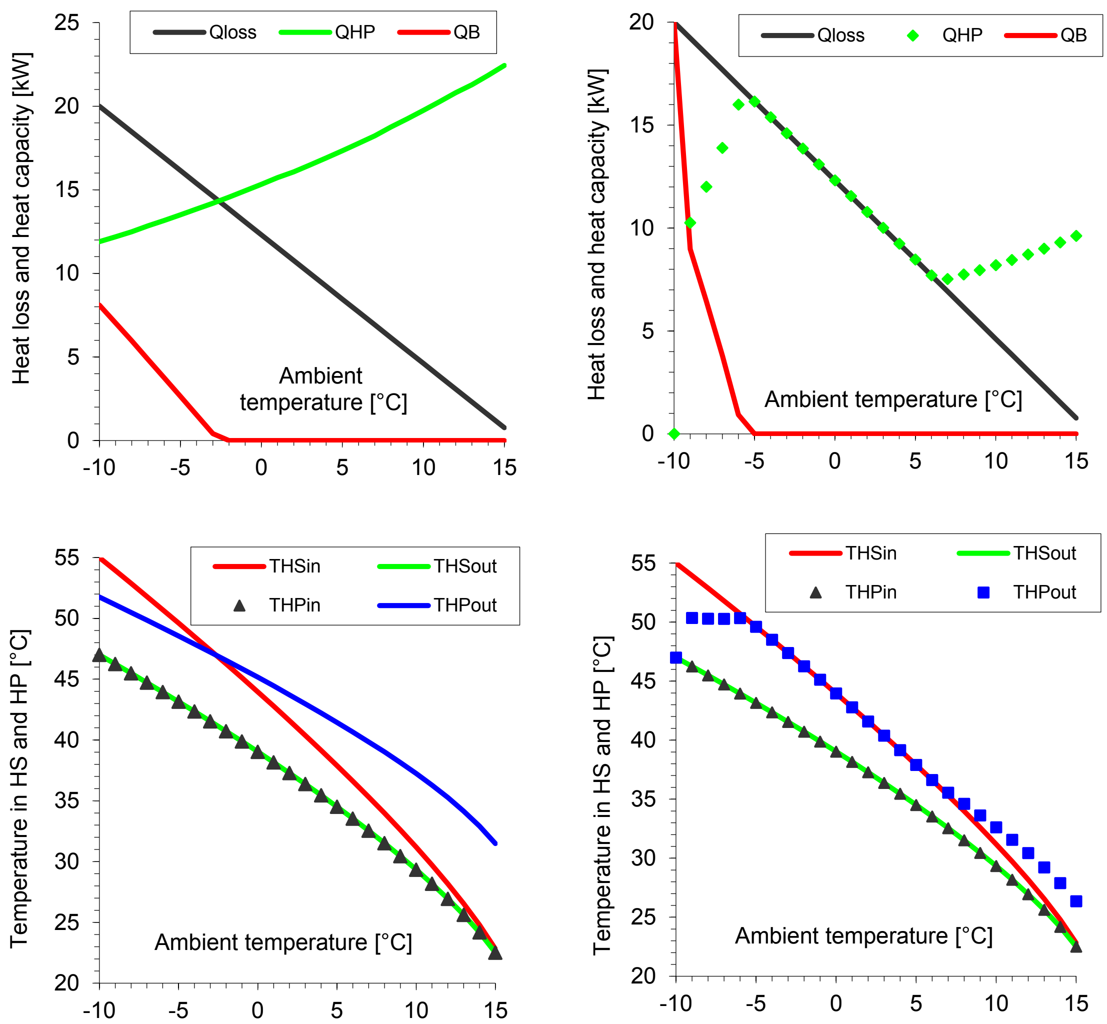

Figure 2. High-temperature heating system 55/47°C with a heat pump and nominal building heat loss of 20 kW (constant speed compressor on the left, variable speed compressor on the right).

In **Figures 3 and 4**, these heat pumps are monitored when used in an object with a nominal heat loss of 30 kW, where the constant speed of the compressor reaches the balance point temperature at +2°C. This temperature is specified in the ČSN EN 14825 and Commission Regulations (EU) No. 811/2013 and 813/2013 as the maximum balance point temperature for the average climate conditions. This size of the heat pump with a compressor ZH15 compressor with constant speed is suitable for objects in the average climatic area up to this nominal heat loss. Therefore, the behaviour of the heat pump is not monitored in buildings with a higher nominal heat loss than 30 kW in this paper.

It is important to note that the HP with a variable speed compressor in the HS of 55/47°C with a nominal heat loss of 20 kW (**Figure 2**) could no longer work at the ambient temperature of –10°C, in that with a heat loss of 30 kW, it works properly with a heating capacity of about 9.7 kW. This is due to the fact that, when demanding higher capacity, it operates at higher speed corresponding to a wider operating range.

In **Figure 5**, the operating areas of both compressors are specified for refrigerant R410A, depending on the evaporation temperature t_o and the condensation t_c. For the cooperation of variable speed compressors with a high temperature HS (e.g. the observed 55/47°C), the slightly lower condensation temperature compared to the fix speed compressor and the reduction of the operating area at high or low frequencies as shown in the right part of **Figure 5** are unfavourable.

For effectiveness description, the Coefficient Of Performance (COP) is used as the ratio of heating

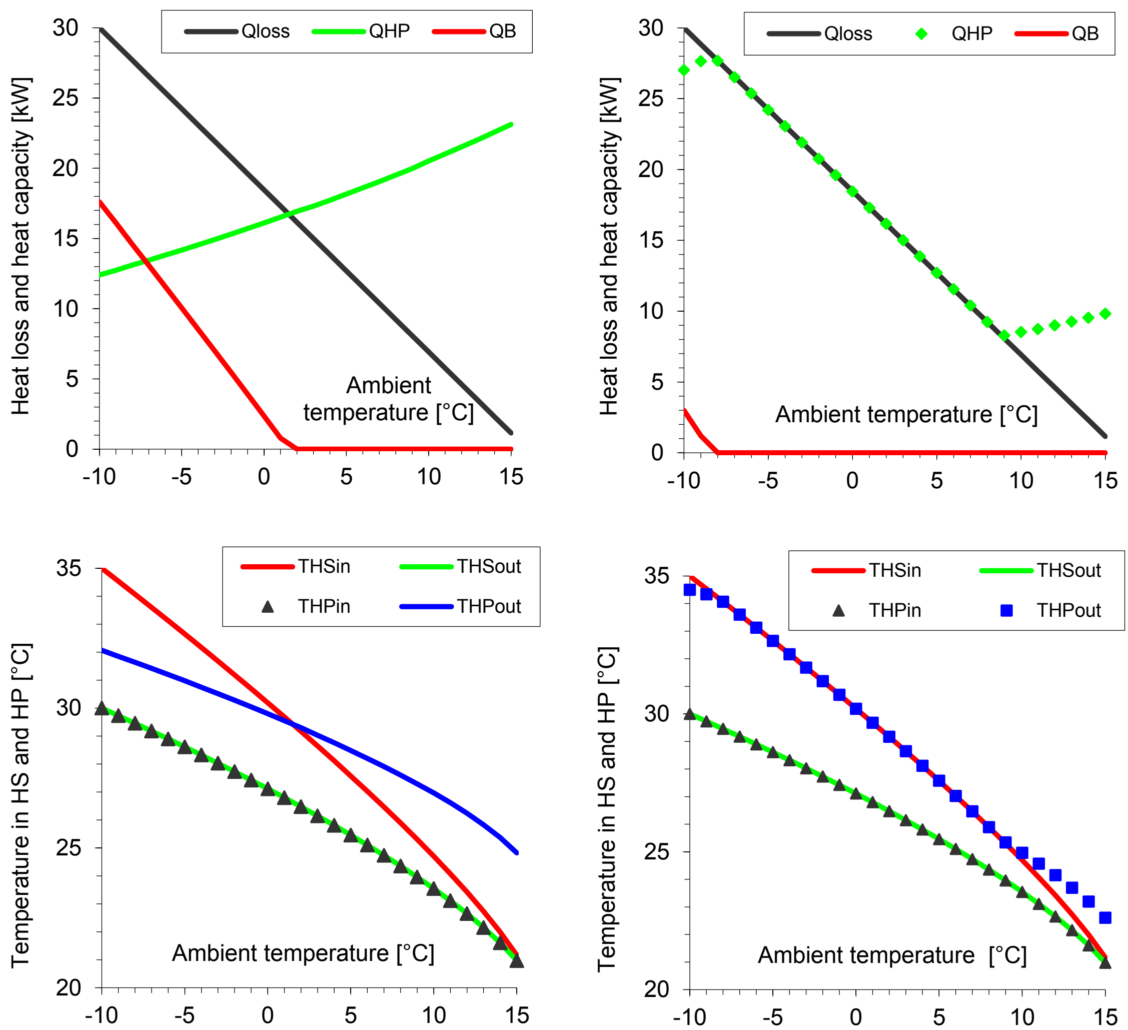

Figure 3. Low-temperature heating system of 35/30°C, heat loss of the building of 30 kW (constant speed compressor on the left, variable speed compressor on the right).

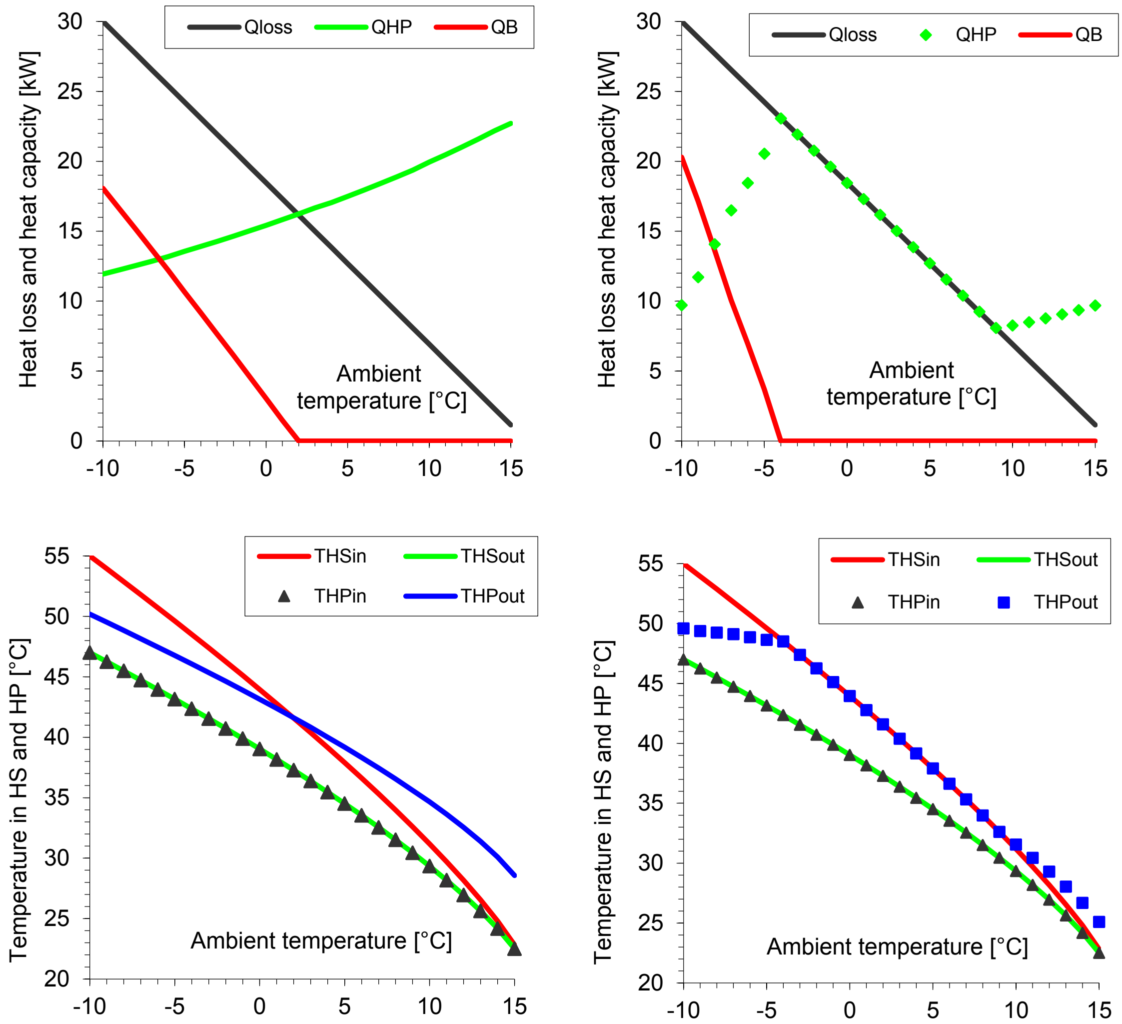

Figure 4. High-temperature heating system of 55/47°C, heat loss of the building of 30 kW (constant speed compressor on the left, variable speed compressor on the right).

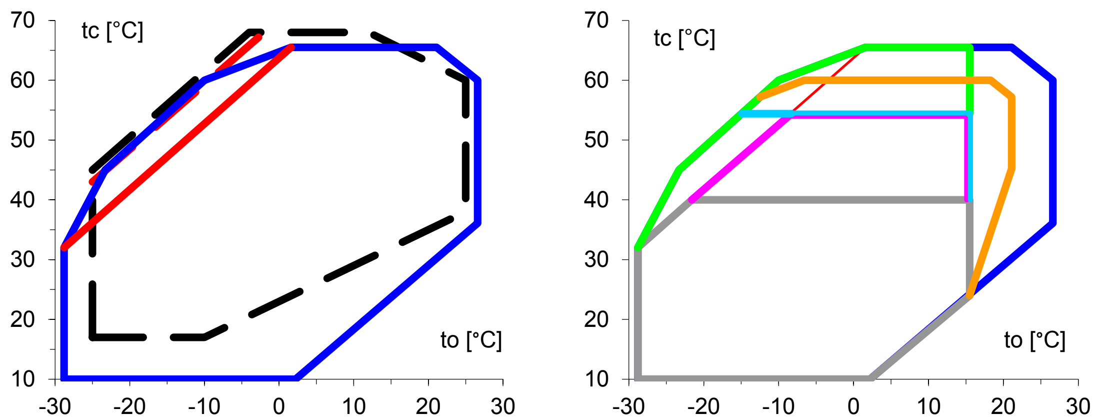

Figure 5. The operating zone of the employed compressors (valid for overheating at the inlet at 5K; the zone is limited by red line for overheating at 10 K): dashed line for the ZH15K1P-TFM compressor with constant speed; solid line for the ZPV0631E-4E9 compressor with variable speed (dark blue 43 Hz to 100 Hz, grey 20 Hz, purple 30 Hz, green 40 Hz, orange 110 Hz, light blue 120 Hz).

capacity to the input power. Today, ČSN EN 14825 defines a total of 8 types of numerals that distinguish between the indices with the abbreviation *COP* or (if associated with a certain period of time) it has the *SCOP* designation and specifying the added index if it is only for the HP (then *SCOP*net) or includes the power consumption by an additional source (*SCOP*on). At the same time, for the purposes of calculating the reference *SCOP*, three reference climate conditions are established: average, warmer and cooler. For these conditions, the range of ambient temperatures and the corresponding heating hours are given. The heating period in all three condition types uniformly ends at an outdoor air ambient temperature of 16°C.

Climate conditions in the Czech Republic are best reflected by the average climate conditions [5]. Therefore, they were used in the calculation of *SCOP*on values and for the determination of the annual energy savings. For simplification, this is understood as the difference between the thermal energy delivered to the HS and the electricity required for the operation of the compressor and an electric heater as the additional bivalent heat source. Results are shown in **Figures 6 and 7** for the assumed use of the heat pump in buildings with a nominal heat loss of 10 kW to 30 kW where COP also reaches their maximum.

A large heat pump in a building with a low heat loss means a large investment cost, but according to **Figure 7**, has a small energy saving, i.e., a long payback period. Besides that, there is also a risk for a variable speed compressor in high-temperature heating systems that the low compressor speed restricts the permissible operating limits below temperatures required by heating system, so the heat pump cannot be operated for a major part of the heating period although it is oversized. This is the reason for the missing data of around 10-11 kW for heating the system of 55/47°C in **Figures 6 and 7**. It is, therefore, necessary to install a heat pump of appropriate capacity relative to the size of the object and to operate it at the higher speed of the compressor.

Although, in **Figures 1–4**, a heat pump with a variable speed compressor better follows the needs of the heating system, the improvement of the seasonal *SCOP*on is only about 10% relative to a compressor with a constant speed in buildings with a heat loss of 15 kW to about 22 kW (for a heating system of 55/47°C, approx. 8% only). The explanation can be found in the weaknesses of the variable speed compressor, namely its working area (see **Figure 5**), as well as the higher energy demand of its operation, which is illustrated in **Figure 8** by comparing the specific compression work based on the manufacturer's data shown.

It should be noted that **Figure 8** does not compare the parameters of the HP, but only the compressors. For a variable speed compressor, this variable also depends on the frequency and its values fill the area defined in the figure with red lines.

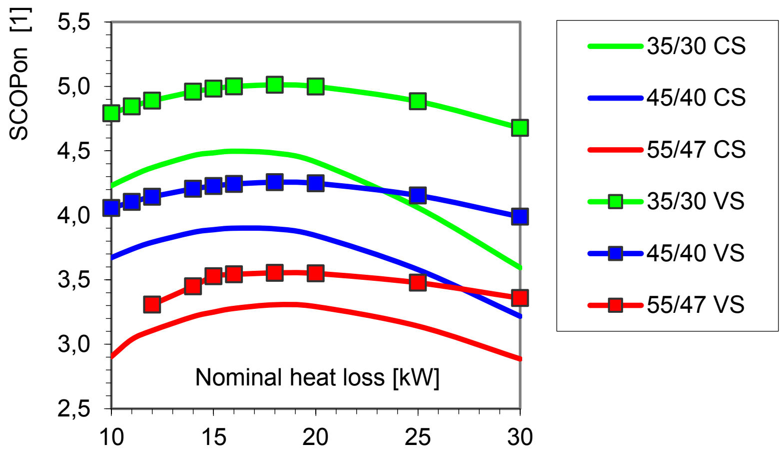

Figure 6. Seasonal Coefficient of Performance SCOPon for different heating systems: CS – constant speed compressor; VS – variable speed compressor.

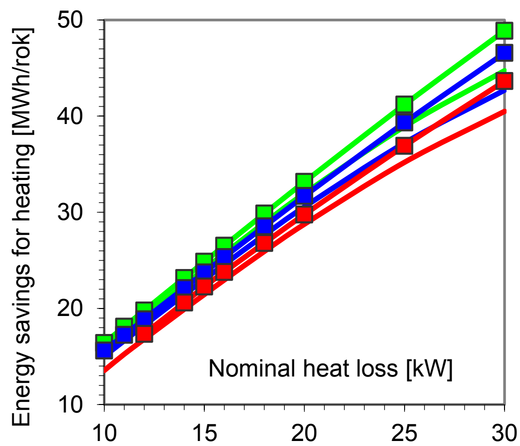

Figure 7. Energy savings for heating: CS – constant speed compressor; VS – variable speed compressor.

In buildings with a nominal heat loss of above approx. 22 kW, the *SCOP*on of a given heat pump with a constant speed compressor is continuously decreasing. This is due to the gradual increase in the balance point temperature and, hence, the longer operation of the bivalent heat source of higher capacity. On the contrary, a heat pump with a variable speed compressor can increase the capacity due to a higher frequency and has a flatter characteristic of the seasonal *SCOP*on, which can be up to 16% till 30% higher than the constant-speed heat pump of the same performance. To improve the heating factor of a constant speed compressor system in such large buildings, it would be necessary to choose a higher performance compressor.

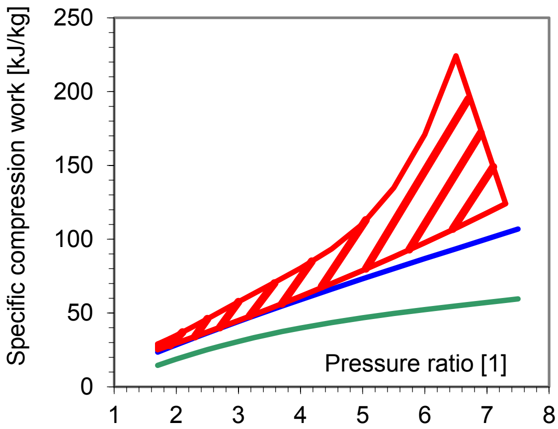

Figure 8. Specific compression work in dependence on the discharge to inlet pressure ratio for the isentropic compression (green) and for the ZH15K1P-TFM (blue) and the ZPV0631E-4E9 (red; hatched area for permissible speed range) compressors.

Conclusion

In this paper, heat pumps differing only from compressors (constant speeds and variable speeds varying in the range of 20 to 120 Hz, but approximately equal displacement of 11.7 and 11.0 m³/h at 50 Hz) were compared. The heat exchangers were identical in both designs (with the same characteristics). Any heat losses due to the heat accumulation have not been considered. This may, in fact, handicap the variant with a constant speed compressor, as the heat accumulation often occurs.

For objects with a nominal heat loss of about 15 kW to 22 kW, a heat pump with variable speed can achieve a better seasonal *SCOP*on by about 10%. In those of 30 kW, this can even be by 16 to 30% depending on the heating system. Due to the increase of the heating capacity by increasing the speed, a heat pump with a compressor of a similar displacement (at 50 Hz) can cover larger objects, but smaller objects (due to the compressor size) may have problems in connection with the significant reduction of the working range (especially heating systems with high water temperatures). A smaller variable speed compressor (with smaller displacement) than for a heat pump with a constant speed compressor will suffice for such an object. ■

Acknowledgement

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References

[1] ČSN EN 14825 – Klimatizátory vzduchu, jednotky pro chlazení kapalin a tepelná čerpadla s elektricky poháněnými kompresory pro ohřívání a chlazení prostoru – Zkoušení a klasifikace za podmínek částečného zatížení a výpočet při sezónním nasazení. *(Air conditioners, liquid chilling packages and heat pumps, with electrically driven compressors, for space heating and cooling - Testing and rating at part load conditions and calculation of seasonal performance.)* ÚNMZ, 2014.

[2] Commission Regulation (EU) No 811/2013 of 18 February 2013 supplementing Directive 2010/30/EU of the European Parliament and of the Council as regards the indication of energy labelling of heater for domestic heating space heaters, combined heaters, sets consisting of a heater for indoor heating, a temperature controller and a solar system, and sets consisting of a combined heater, a temperature controller and a solar system. Official Journal of the European Union L 239, p. 1-82 of 6 September 2013.

[3] Commission Regulation (EU) No 813/2013 of 2 August 2013 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco-design requirements for indoor heaters and combined heaters. Official Journal of the European Union L 239, pp. 136-161 of 6 September 2013.

[4] Design Software by Copeland: Select, version 7.13.

[5] PETRÁK, J., KOLOVRATNÍK, M., PETRÁK, M. Teplota vzduchu v otopném období z pohledu legislativy. (*The Air Temperature in the Heating Season in Terms of Legislation).* Vytápění, větrání, instalace *(Journal of Heating, Ventilation and Sanitary Installation)* 3/2017, pages 144–148. ISSN 1210-1389.

Healthy Low Energy Redesigns for Schools in Delhi

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Indoor air quality and thermal comfort of existing naturally ventilated classrooms in the Indian capital territory, Delhi, is substandard. This should be improved while trying to prevent the increase in energy demand. The research question focused on solution options to answer these contradictory requirements.

Introduction

New Delhi, India's capital city, is burdened with highly polluted outdoor air and an extreme climate. These conditions can adversely affect health and learning of children in classrooms without mechanical ventilation and cooling, see **Figure 1**.

Since children's lungs are still developing, they are more vulnerable to air pollution than adults. Continuous exposure to polluted air can disrupt lung development {CPCB, 2008}, leading to reduced lung function and even chronic respiratory diseases {Kumar, 2008}. Currently, as an extreme measure, the Indian government has to resort to shutting down schools on hazardous days, i.e., days when the particulate matter ($PM_{2.5}$) hits hazardous levels (>300 µg/m³). This is no long-term solution for the over 600 000 Indian schools. Even a small step to improve indoor air quality in these schools can have a major impact on the lives of millions of children.

Sustainable improvement

India also has a growing energy problem due to the rapid population growth and being an emerging economy {Wang, 2016}, with demand transcending supply. In order for India to reach its economic and social targets, the energy infrastructure is potentially India's main challenge {Tripathi, 2016}. The energy usage (already 5% of the world's energy) continues to grow in an unsustainable manner, being based primarily on fossil fuels. This, consequently, also contributes to outdoor air pollution {Wang, 2016}.

These circumstances make it abundantly clear that it is important to sustainably improve the indoor climate (IC) in existing, naturally ventilated classrooms in places like Delhi in order to restrain the energy demand. Beyond environmental concerns, the extra energy and investment costs can also become a giant burden for such schools. Even so, sustainably improving the health in governmental schools is both socially and economically valuable in the long term. It can stimulate teachers to improve education and can provide better social opportunities for economically disadvantaged families {Garg, 2006}. Subsequently, the sustainable schools will set a socio-economic example for the energy reformation and the market-oriented economy {Swaminathan, 2016}.

First step

This study was set to develop generic, sustainable, indoor climate improvement packages for a typical, naturally ventilated classroom in Delhi. Solutions easily available in local market, passive, and of "plug and play" type were preferred. However, entirely relying on passive solutions may not suitably address the risks of exposure to particulate matter. To design these packages an inventory of the current condition was necessary. Therefore, a field study was deemed necessary.

The final packages were designed and evaluated based on IAQ, thermal comfort, energy use, and (financial) feasibility. We presume that solutions developed for Delhi conditions could be extrapolated to other regions of India by taking into account climatic differences for indoor thermal conditions while IAQ concerns would remain similar – or even less demanding – in other regions.

School visits

Between 10 September and 11 October 2017, five schools in and around Delhi were visited. In total, 15 teachers were surveyed regarding their perception of the classrooms' indoor environmental quality (IEQ), covering thermal comfort, air movement, humidity, air quality, noise, and lighting. Additionally, indoor air temperature (T_{in}), outdoor air temperature (T_{out}), relative humidity (RH), surface temperature, indoor air velocity, carbon dioxide (CO_2) concentration, and $PM_{2.5}$ concentration in the classrooms were measured (see **Figure 2**).

The survey showed that roughly 11/15 of the teachers were at least slightly warm at time of measuring, though still 12/15 were satisfied with the thermal conditions. Most teachers expressed some dissatisfaction regarding the thermal condition during peak summer and winter periods. Even though the study fell during monsoon, 8/15 were satisfied with humidity conditions. Additionally, 12/15 did not experience dissatisfaction with the IAQ. Seemingly, teachers had a hard time judging the IAQ, being only able to associate it with coarse dust and 'fresh' outdoor air.

Depending on the classroom and occupancy, the mean indoor CO_2 concentrations per classroom were between 50 and 300 ppm above outdoor CO_2 concentration, when doors and windows were opened, and fans were

Figure 1. Example of naturally ventilated classroom.

Figure 2. Two hours measurement in reference classroom.

running. These conditions correspond to ACH rates of roughly 17 to 24 [1/h]. This fluctuation is related to the opening sizes, solar shading, fans, and cross ventilation. The high ACH rates results in high $PM_{2.5}$ infiltration rate and an indoor to outdoor ratio of roughly 1, as can be seen in **Figure 3.**

The thermal conditions in the classrooms differed with their orientation, exposure to outdoor conditions, and occupancy. T_{in} was roughly deviating 1°C from T_{out}. The classrooms tend to be 0.5°C cooler compared to the hallway, at least during the morning session. The mean radiant surface temperature varied 0.5°C from the T_{in}, depending on the surface construction and orientation. This indicated that T_{in} was little affected by the radiant temperatures.

Development of numerical model

The field measurement results, together with the corresponding inventory, led to the boundary settings for the base model. The model is executed in TRNSYS 18 using the building model Type 56. The numerical model is designed with a relatively low resolution as this already gives sufficient information to evaluate the necessary interventions to achieve a healthier and more comfortable IEQ (Djunaedy, 2012). For example, the model assumes a constant natural ventilation rate, while in reality, the wind pressures around the building and occupancy patterns were fluctuating, affecting the indoor climate. We compared the modelled CO_2 concentration towards a measurement and concluded that the model was able to spot the same peak.

The National Building Code of India (NBC, 2016), in combination with IEQ standard (ISHRAE, 2016), led to the IEQ performance goals for this research. Thermal comfort was evaluated based on the adaptive thermal comfort (ATC) model for mixed mode and naturally ventilated buildings. The IAQ was evaluated based on ISHRAE standards Class C (ISHRAE, 2016), which is in line with the air quality guidelines as given by the World Health Organisation (WHO, 2005). Thence, the threshold value for CO_2 is 750 ppm above the ambient concentration and the daily average $PM_{2.5}$ threshold is <25 µg/m³.

Indoor climate simulation results

In winter, the outdoor temperatures drop towards 12°C. As the schools are unequipped with any heating, the windows are kept closed to keep warm. Still the uninsulated façade causes high heat losses and cold infiltrating air, leading to under heating hours with indoor temperatures towards 15°C. Additionally, the lack of fresh air results in CO_2 exceeding hours. Still, the outdoor hazardous pollutants keep infiltrating into the indoor environment (above 100 µg/m³).

In mid-season, the windows are opened, and the fans are off. The natural ACH rate seems just sufficient to keep the CO_2 concentration within the limit. Though, the smallest decrease in ventilation leads to CO_2 exceedance hours.

Delhi has two hot seasons, the dry summer and the rainy monsoon. During both seasons, the windows are fully open and fans are running. Especially during summer, T_{op} is frequently above the neutral temperature. Classrooms on the top floor are particularly hot due to the additional rooftop solar load. The indoor CO_2 concentration is always below the threshold due to high natural ventilation rates. Furthermore, the outdoor $PM_{2.5}$ concentration is usually below 100 µg/m³.

Table 1 shows the indoor climate and energy performance for one school year.

Improvement packages

These nested problems may not be resolved by any single intervention. For example, to reduce the CO_2 exceedance hours, ventilation rate should be increased in winter.

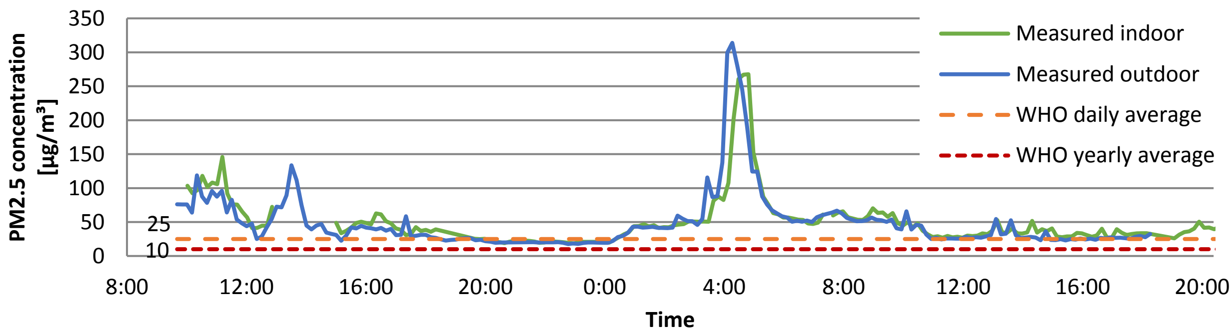
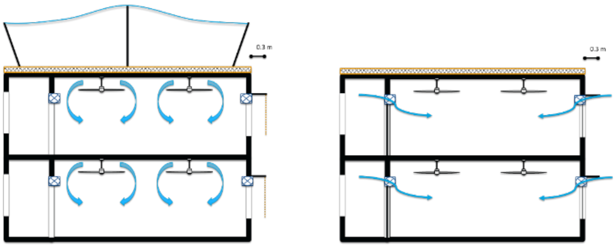
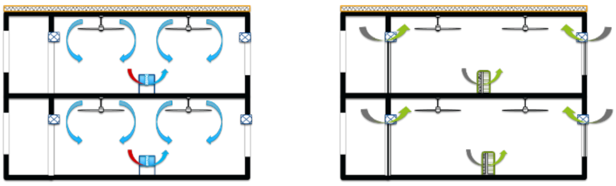


Figure 3. Example of measured indoor and outdoor concentrations of fine particulate matter $PM_{2.5}$ compared to WHO guidelines, at school 1 on 11/07/2017-12/07/2017.



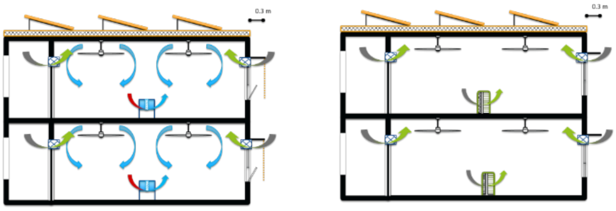
(a) *(b)*

Figure 4. Schematic representation of package 1, with retrofitted single glazing, roof insulation, integrated window purifying ventilators, bamboo window shading, and summer canopy. (a) in summer (b) in winter.



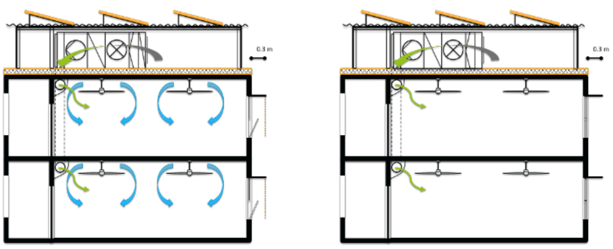
(a) *(b)*

Figure 5. Schematic representation of package 2, with fully operable double-glazed windows, roof insulation, integrated window purifying ventilators, and modular electrostatic precipitator/evaporative cooling. (a) in summer (b) in winter.



(a) *(b)*

Figure 6. Schematic representation of package 3, with partly operable double-glazed windows, roof insulation, bamboo window shading, integrated window purifying ventilators, modular electrostatic precipitator/ evaporative cooling, and solar PV. (a) in summer (b) in winter.



(a) *(b)*

Figure 7. Schematic representation of package 4, with partly operable double-glazed windows, roof insulation, air handling unit with three stage air filtering and cooling coil, and solar PV. (a) in summer (b) in winter.

However, this would also increase the under-heating hours. Instead of adding heating capacity, heat recovery ventilation can be a better option. Additionally, in winter the solar load contributes to heating up the space.

Also, while blocking pollutants from entering the classrooms, sufficient fresh air is required. As active filtering showed to be necessary it is of great interest to create overpressure in the rooms to reduce infiltration.

Besides the necessity of active filtering, it appeared that active cooling is needed to eliminate overheating hours. To this end, evaporative cooling would be more energy efficient than mechanical cooling.

The unilateral interventions were assembled into 4 packages, varying in level of technology, control, and sustainability. Each package may easily be scaled up. Package 1 (**Figure 4**) represents the most low-end decentralised solution by retrofitting window panes and the least amount of active technologies. Package 2 and 3, respectively **Figure 5** and **Figure 6**, are more high-end solution due to the costly application of electrostatic precipitators. The biggest difference is the use of photovoltaics in package 3. Finally, package 4 (**Figure 7**) is the only centralised solution with 3 stage filtered air handling unit.

The package performances are tested concerning the indoor climate, energy, investment costs, and operating costs. All packages are designed such that there is always an ACH rate of at least 7 [1/h] to restrain the indoor CO_2 concentration. The $PM_{2.5}$ exposure (**Figure 8**) is reduced by installing more filtering capacities. Regarding the thermal comfort (**Figure 9**) it is clear that active cooling is necessary to eliminate the overheating hours. Though the increased ventilation capacity in winter causes extra under heating hours.

Table 1. Simulation results of the base case, over one school year (1890 occupancy hours).

Criteria	Base case
Under heating hours [h]	75
Overheating hours [h]	330
CO_2 exceedance hours [h]	250
Annual average CO_2 concentration [ppm]	830
$PM_{2.5}$ exceedance hours [h]	225
Annual average $PM_{2.5}$ concentration [μg/m^3]	115
Electricity use [kWh]	685

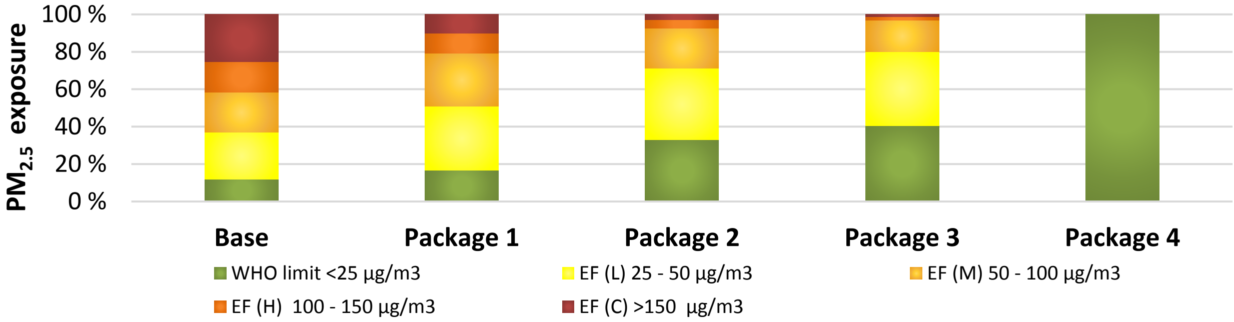


Figure 8. Annual mean indoor $PM_{2.5}$ exposure categorized in exceedance factor (EF) hours - Low (L), Moderate (M), High (H), and Critical (C) - and hours underneath daily WHO limit, over in total 1890 occupancy hours.

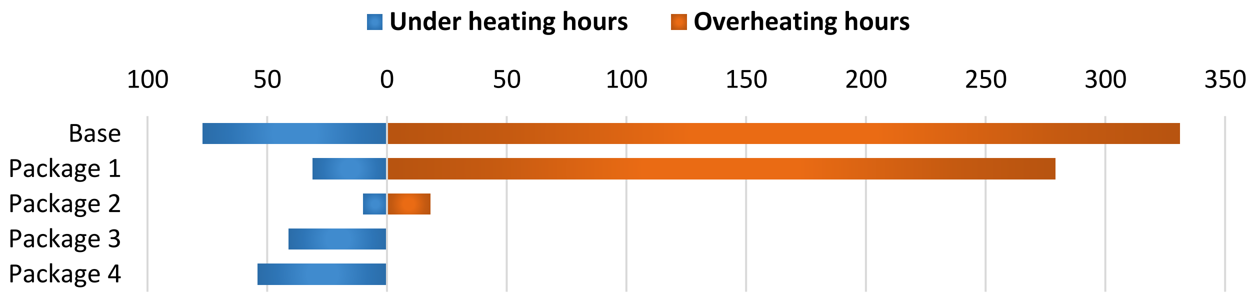


Figure 9. Thermal performance of the different packages in the classroom at the ground floor, expressed in under- and overheating hours outside the 80% satisfaction range of the ATC model with a total amount of occupancy hours = 1890 h.

Subsequently, the packages were ranked via a decision matrix (**Table 2**). The financially most feasible solution, package 1, has the least effect on the indoor climate. Additionally, package 4 scores the best on healthy indoor climate in respect to $PM_{2.5}$. Though financially, it is most infeasible and unsustainable on the longer term due to the high cooling demand. Package 2 scores points on all criteria and therefore scores best overall, whereas package 3 and 4 actually lose points due to an increase in under heating hours. However, on the longer term package 3 is more sustainable and financially feasible.

Table 2. Decision matrix to rate 4 different solution packages (more ★'s = better performance; more €'s = more expensive).

Criteria	Package 1	Package 2	Package 3	Package 4
Under heating hours	★	★★★	–	–
Overheating hours	★	★★★	★★★★	★★★★
CO_2 exposure	★★	★★	★★	★★
$PM_{2.5}$ exposure	–	★★	★★	★★★
Electricity use	★★	★★	★★★	–
Investment costs	€	€€€	€€€€	€€€
Total cost of ownership	€	€€€€	€€	€€€

Conclusion

Via fieldwork and simulations, it is concluded that naturally ventilated schools in Delhi mostly experience high $PM_{2.5}$ concentration, extreme overheating and slightly under heating. Both active air filtering and cooling seem required. As the occupants are used to an open façade (open doors and windows), sealing the classrooms is unacceptable. Instead the openness is decreased by applying partly operable windows and creating an overpressure during hazardous days.

The packages assessment showed that package 3 as decentralised solution potentially is the most effective, sustainably and financially, generic solution to create a healthier indoor climate in such schools. The high investment cost might be attenuated by implementing the package in phases. Though, in order to reach the target to reduce the $PM_{2.5}$ exposure towards the WHO limit, a multiple stage filtering seems necessary. Additionally, it is interesting to integrate a heat recovery into the ventilation system to eliminate the under-heating hours. It might even function as cold recovery to reduce the cooling demand. ■

"Rethinking Comfort": an overview from the Windsor conference 2018

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Research on thermal comfort has been carried out for a long time. The PMV model was developed already about 50 years ago, but still has a major influence in the field. The adaptive comfort approach recognized that thermal comfort is not a fixed phenomenon but is influenced by physiological, psychological and behavioural adaptations. This allows for a larger variation in indoor temperature, along with the variation of the outdoor temperature, thereby enabling reduction of building energy use. Still building energy consumption, global warming, health implications and individual thermal discomfort give rise to new developments in research and design of indoor thermal environments of a variety of building types.

Keywords: Thermal comfort; Personal control; Indoor environment; Health; Heating systems; Climate change; Energy efficiency; Productivity; Sleep; Windsor Conference

The 10th Windsor conference, hosted by prof. Fergus Nicol (NCEUB) and prof. Sue Roaf, was themed "Rethinking Thermal Comfort", giving the attendees the opportunity to share and discuss ideas on new approaches in providing comfort in a changing world. This resulted in a conference program with sessions on the new approaches for heating and cooling, personal control and user behaviour, comfort in different types of building, comfort during sleep and thermal comfort in hot climates. Keynotes addressed the debate on the development in the direction of low-tech versus high tech buildings and the impact of social, economic and cultural experience on thermal comfort. Lastly, workshops facilitated discussions on comfort models, overheating of buildings, research methodologies and health implications of the indoor environment.

In this article we highlight a selection of the studies related to the topics that were presented during the conference (impression in **Figure 1**).

Prediction of thermal comfort

Thermal comfort standards prescribe indoor environments in buildings that should satisfy 80% of the building occupants. A study of Karmann et al. investigated if this matches the votes from occupants in real world buildings. Investigation of 351 office building in North-America revealed that 43% of all occupants were in general thermally dissatisfied, 19% were neutral and 38% were satisfied (N=52980). The percentage of buildings with 80% or more satisfied occupants was only 2% (8% when including the neutral votes) (**Figure 2**). These concerning results were hypothesized to be attributed to the inability of the large majority of HVAC systems in providing personalized conditioning or opportunities for personalised control. The results imply that many buildings do not create an indoor environment that occupants consider satisfactory [1]. The study addresses the deviation of a real-world thermal satisfaction from prediction, thereby indicating the influence of individual thermal preference.

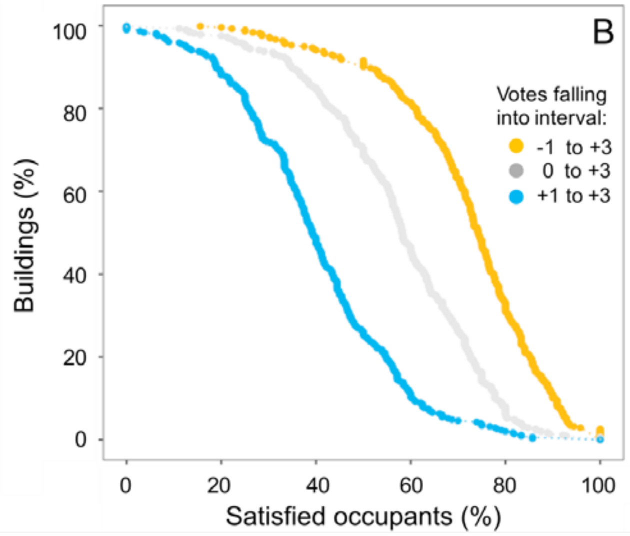

Figure 2. Line graph showing the percentage of buildings meeting given percentage of occupants satisfied with temperature. The analyses are conducted for 3 satisfaction criteria ("-1 slightly dissatisfied to +3 very dissatisfied"; "0 neutral to +3 very dissatisfied"; "+1 slightly satisfied to +3 very dissatisfied"). Figure obtained from Karmann et al. 2018.

Personal control and preference

Several studies presented at the conference aimed to improve individual thermal satisfaction by applying personal control opportunities and personal thermal comfort models in the indoor environment. In a field study by Pigman et al. the responses to windows and fans in three buildings were investigated to study the effect of personal control on overall satisfaction with the indoor environment. The surveys revealed that

Figure 1. Discussions and presentations during the conference.

occupants appreciate the operable windows and fans. Satisfaction with the environment was however not significantly related to just having access to personal control, but with perceived control and the ability to control the indoor environment parameters. These results are line with previous findings of Boerstra (2016) and emphasise the need of providing effective control opportunities, and to educate people in how to use them [2].

To predict and anticipate on individual thermal comfort response, the study of Kim et al. provided a framework for personal comfort models and how these can be integrated in indoor environmental controls. Using the Internet of things and machine learning, individuals' comfort requirements can be obtained. Challenges and opportunities for the application of personal comfort models include collection of data feedback, generalisation to larger populations and different thermal preferences in shared spaces. Monitoring of the thermal behaviour, analyses on repeatable patterns between different individuals in large samples and personal comfort systems are relevant aspects in resolving these issues [3]. Additionally, a self-learning framework was proposed by Zhao et al. and focussed on personalised thermal comfort considering that each occupant has a unique thermal preference. Learning algorithms to build a personal level comfort model may provide the basis of personalised dynamic thermal demands. The model may also help to give a better understanding between the internal links between psychology, physiology and behavioural aspects [4]. All imply that personalized components to the workplace are required to improve satisfaction with the indoor environment. Self-learning algorithms and data collection using IOT can assist in providing individually tuned workplace environments and to increase knowledge on the influence and interaction between psychological, physiological and behavioural aspects.

Interactions between different indoor environmental parameters

According to Foo and Mavogianni, thermal perception is associated with expectations of the physical environment. Therefore, they investigated the effect of interior finish characteristics on thermal comfort in learning spaces. Thermal comfort was evaluated ant a systematic characterisation of the interior finish was developed. Small but significant effects of the naturalness of the materials and the colour tones were found: thermal comfort was higher in lecture rooms with natural materials and when warm colour tones were used [7]. The latter confirms the hue-heat hypothesis, which states that a room that is illuminated by light towards the warm end of the spectrum is perceived as warmer compared to light dominant in the cool part of the spectrum. A study of te Kulve et al, also investigated the effect of visual perception on thermal comfort and/or thermal sensation. In a laboratory study the effect of the correlated colour temperature and illuminance of light on thermal perception was tested. There was however no significant effect of correlated colour temperature or the intensity of light on thermal sensation or thermal comfort in this study. Interestingly, the change in visual comfort between light sessions was related to the change in thermal comfort for the same ambient temperature. This implies that visually comfortable conditions may improve thermal comfort, but individual preferences should be considered [5]. Chinazza et al. evaluated the influence of light levels on thermal perception in a real-world environment during the summer and winter. Their results show that in both seasons thermal satisfaction was higher at illuminances >300 lux (illustrated in **Figure 3**). Especially in summer when indoor tempera-

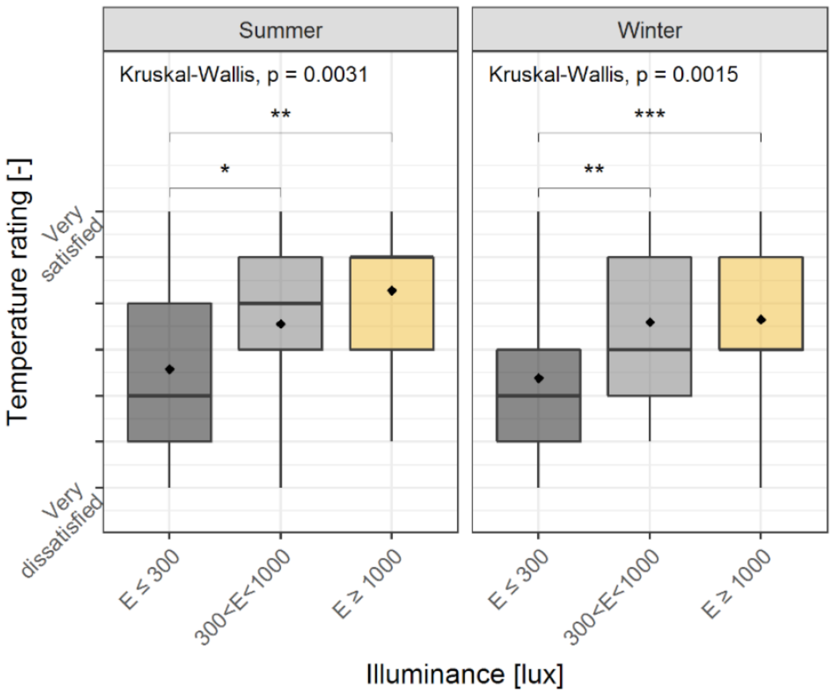

Figure 3. Thermal evaluation responses according to the two seasons and the illuminance levels. Thick line: median; diamond: mean. Figure obtained from Chinazzo et al, 2018.

ture was >25°C thermal satisfaction was clearly lower when exposed to low light levels (<300 lux) compared to exposure to brighter light. The results were assumed to be explained by the thermal expectations indicated by the light intensity e.g. a higher light intensity results in a higher expectation of the temperature [6]. These three studies indicate that thermal satisfaction and thermal comfort is affected by visual perception of the environment. Expectations raised from and appraisal of the visual environment may interact with thermal evaluation.

Comfort and health implication of the indoor environment in different building types

Different buildings types have different requirement for the design of a healthy and comfortable indoor environment. In predicting thermal satisfaction in HVAC buildings, in this case a fully air-conditioned museum, a study of Kramer et al. showed that this building does not adheres its typology of being a HVAC building in terms of thermal comfort. The acceptability of seasonal variation was larger, clothing behaviour corresponded that of naturally ventilated (NV) buildings, mean thermal sensation was under estimated towards the cold and warm end of the thermal spectrum and the outdoor temperature significantly influenced thermal sensation indoors. Though the indoor temperature range matched that of HVAC buildings. So, the categorisation of buildings solely based on HVAC or NV is not sufficient for predicting thermal sensation in museums [8].

The paper of Nikolopoulos analysed thermal comfort in different contexts; in offices, outdoor urban spaces and airport terminals. Airports have very different user groups with different requirements for thermal comfort. The study tested if the needs of staff are more like offices workers and if passengers' requirements, who use the building a transition area, are closer to the outdoor environment. Indeed, the results show that employees and office workers are more acclimated to the working thermal environment and comfort temperatures are closer to the mean operative temperature. Passengers on the other hand, demonstrate a wider adaptation capacity, like in urban spaces [9]. Differences in expectation probably partly explain this observed dissimilarity.

Classrooms function quite different from other building types. A review of Kumar Singh et al. about thermal comfort in school buildings found that in each education level (primary school, secondary school and university), students were highly dissatisfied with the indoor thermal environment. This while the quality of the thermal environment influences school performance and wellbeing of the students. Specific guidelines for the design of the indoor environment in school is therefore desirable. The comfort temperatures in schools obtained in the selected studies will be used to develop an adaptive comfort equation for primary, secondary and university classrooms [10]. Another type of buildings with specific demands are nursing homes. In six Australian nursing homes, the thermal environment was measured and the impact on the perception and comfort of staff, residents and other occupants was investigated by Tartarini et al. The results of their study show that nursing homes do not provide thermally comfortable conditions for occupants during both summer and winter. Residents prefer a higher temperature (0.9°C) and wear more clothes compared to non-residents. Further research is required to support the development of best practice guidelines [11].

These studies all indicate that thermal satisfaction in buildings largely depend on the function of a building and differs between users' group within a building.

Dwellings

In European residential buildings the indoor environment problem is more related to negative health effects. Analyses of the EU-SILC database by John et al. showed that one out of six homes in Europe can be categorised as "unhealthy". In this case, "unhealthy" is defined as buildings that have damp, a lack of daylight, inadequate heating during winter or overheating problems. The probability that a person reports poor health increases with 70% when living in an "unhealthy building". Although there are of course many other factors influencing a persons' perceived health, individual and societal health would benefit from indoor environmental improvements in buildings and specifically in homes [12].

Performance of renovated buildings in winter and different heating systems

New and renovated buildings need to be well insulated to reduce the required energy for heating and cooling. Low temperature radiation systems are often applied in these buildings. Therefore, the study of Safizadeh and Wagner investigated thermal comfort for four different scenarios of a low temperature heating. These consisted of combinations of a heated ceiling with a temperature of 28 and 35°C and a distance from the window of 1 and 3 meters. The study results show that during a 60 minutes exposure; i) it is possible to achieve mostly neutral thermal sensation votes using low temperature heating, even close to the window (if regulation of energy efficient buildings are used); ii) overall thermal sensation followed the local votes at the upper-body parts, iii) surprisingly, the head was perceived as the most comfortable body part; iv) lower body limbs and hand were the least comfortable limbs; v) for the different scenarios, thermal comfort votes had a wide range at the lower limbs and hand; vi) unlike local comfort votes, the local sensation was strongly related to the local skin temperatures. Further studies will be carried out to be able to develop a comfort model for asymmetric condition as created by radiant systems [13].

Climatic adaptions to temperatures and its effect on preferred temperature and health

Globalisation leads to a working environment where people with different comfort and climatic background work. Hence it was investigated whether building occupants' comfort rating are affected by climatic background. A post-occupancy evaluation was carried out by Pastore and Andersen in two office buildings located in Switzerland (high rate of international employees). The result of the surveys indeed revealed that thermal comfort and air quality ratings were affected by the climate of origin and the time spent in the country (as shown in **Figure 4**) [14].

The effect of climate on preferred indoor temperature was also shown by a study by Mino-Roderiguez et al., who investigated the preferred temperature in houses in the subtropics. The differences in temperature preference of people living at a high and a low altitude was of interest. The highlands in the tropics are characterised by a narrow annual temperature oscillation and a noticeable diurnal temperature variation combined with high levels of solar radiation. At low altitude, the tropics are hot and humid. The study revealed that the acceptable indoor temperature range in the highlands was lower, between 16°C–-24°C compared to 26°C at the low-altitude. People at high-altitude were more sensitive to draft, whereas people at the low altitude prefer higher air movement [15]. These results also indicate that people get used to a certain range of ambient temperatures, thereby affecting their preferred temperature.

Adaptation to ambient temperatures may not only affect preferred temperature, but also impact health. Regular exposure to temperature outside the thermal neutral zone might have positive implications for metabolic and cardiovascular health. Pallubinsky et al. studied the effect of acclimation to mild heat (34°C) in overweight elderly men. After 10 days of acclimation, fasting plasma glucose levels, fasting plasma insulin values and HOMA-IR were significantly decreased, which implies effect of passive mild heat acclimation on glucose metabolism. Additionally, core body temperature and mean arterial pressure were lower during thermoneutrality and warmth. The results indicate positive health effects for this study group as cardiovascular diseases are common in overweight and elderly people [16]. The studies show that the human body and its thermal perception is not fixed but can adapt to higher or lower temperatures. Exposure to elevated temperatures may even be beneficial for health.

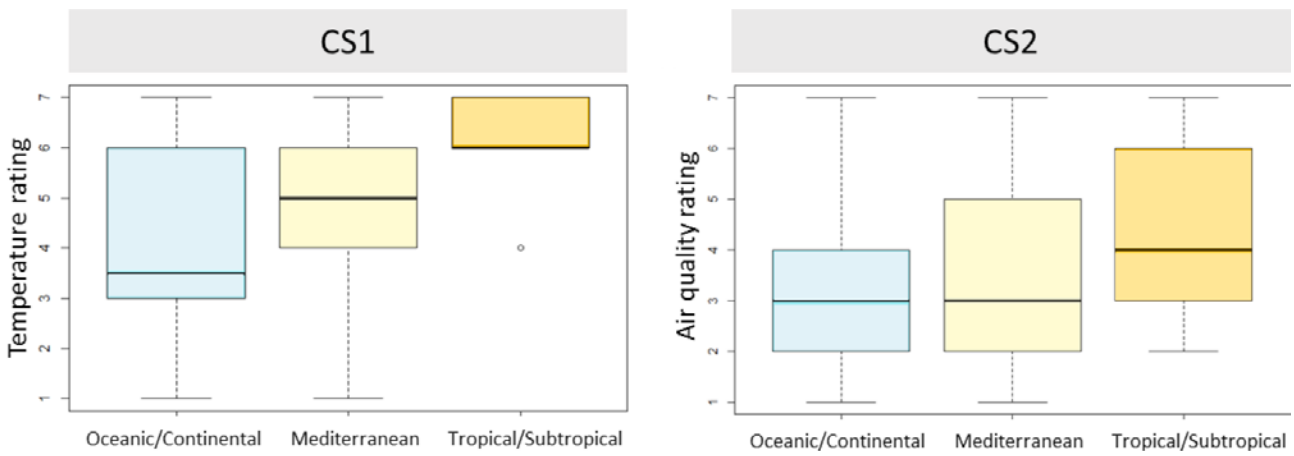

Figure 4. Rating distributions for temperature in Case Study 1 (CS1) (left) and air quality in building CS2 (right) based on climate of origin (1 corresponds to "Very dissatisfied" and 7 to "Very satisfied"). Figure obtained from Pastore and Andersen, 2018.

Thermal comfort to enhance sleep and next-day productivity

Thermal comfort studies are carried out to improve satisfaction with the thermal environment. The importance of providing thermally comfortable environments is strengthened when looking at the impact of the ambient temperature on sleep quality and on next-day productivity. The paper of Nicol and Humphreys provides starting points for a model on the effect of bedroom temperature on comfort and sleep quality. For a sleeping person, the desired temperature around the body is 29-32°C. Sleepwear and bedclothes allow for adaptation to the indoor temperature and a well-insulated matrass lowers the comfortable room temperature. Maximum bedroom temperatures should avoid discomfort and sleep loss [17]. In a field study in university dormitories by Zhang et al., the effects of indoor environmental parameters, including room temperature, on sleep quality were investigated. The study results indicate that people felt more neutral and less sensitive to the thermal environment during sleep (as subjectively evaluated just after waking-up) compared to being awake. In this study, the indoor temperature that resulted in the highest temperature satisfaction during sleep was 24,2 °C. Different indoor environmental factors were interrelated and therefore more research is needed to address the individual effects [18]. This is highly relevant because improving sleep quality can enhance next day performance.

Thermal environment and productivity

The daytime indoor environment can also improve performance during the day. Gupta et al., studied the relationship between the indoor environment and workplace productivity in a naturally ventilated office. The results show that self-reported productivity decreased when the indoor temperature and CO_2-concentrations increased [19]. These three studies emphasise that studies on desirable indoor environmental conditions should not only focus on comfort but should also evaluate how it affects the activities carried out in the room e.g. sleeping or performing office tasks.

Concluding remarks

This overview of current research topics related to thermal comfort show that:

- Prediction of thermal comfort solely based on the designed physical environment does not match real comfort op building occupants.
- Attention should be paid to the wide range of factors influencing thermal perception (building type, function, user groups, overall experience and expectations).
- Technology can be used to make systems more efficient, self-learning and personalised, thereby enhancing individual comfort.
- Design and research on thermal environments should not only focus on comfort but should also incorporate effects on health and productivity, thereby increasing its social relevance.

Figure 5. Group picture in front of the Cumberland Lodge at Windsor Great Park.

In conclusion, research on thermal comfort and development of new heating and cooling strategies are highly relevant to be able to anticipate on current developments such as global warming and the need the reduce building energy consumption. ■

Acknowledgements

The organising committee of the 10th International Windsor Conference is greatly acknowledged for hosting the interesting meeting at the Cumberland Lodge, Windsor Great Park, UK 12th-15th April 2018.

References

Papers presented at the conference that were included in this overview:

1. Karmann, C., Schiavon, S., Arens, E. Percentage of commercial buildings showing at least 80% occupant satisfaction with their thermal comfort.
2. Pigman, M., Brager, G., Zhang, H. Personal control: windows, fans and occupant satisfaction.
3. Kim, J., Schiavon, S., Brager, G. Personal comfort models - new paradigm in thermal comfort for occupant-centric environmental control.
4. Zhao, Y., Carter, K., Wang, F., Uduku, O., Murray-Rust, D. Self-learning Framework for Personalised Thermal Comfort Model.
5. te Kulve, M., Schlangen, L., van Marken Lichtenbelt, W. Light exposure effects on the perception of the thermal environment
6. Chinazzo, G., Pastore, L. Wienold, J. Andersen, M. A field study investigation on the influence of light level on subjective thermal perception in different seasons
7. Foo, J., Mavrogianni, A. Seeing is believering or is it? An assessment of the influence of interior finish characteristics on thermal comfort percpeiton at an University campus in a temperate climate.
8. Kramer, R., Schellen, H., van Schijndel, J., Zeiler, W. Reliability of characterising buildings as HVAC or NV for making assumptions and estimations in case studies.
9. Nikolopoulou, M., Kotopouleas, A., Lykoudis, S. From indoors to outdoors and in-transition; thermal comfort across different operation contexts.
10. Kumar Singh, M., Ooka, R., Rijal, H.B.Thermal comfort in Classrooms: a critical review
11. Tartarini, F., Cooper, P., Fleming, R. Thermal comfort for occupants of nursing homes: A Field Study.
12. John, A., Hermelink, A., Galiotto, N., Foldbjer, P., Bjerre, K., Eriksen, M., Christoffersen, J. The impact of the quality of homes on indoor climate and health: an analysis of data from the EU-SILC database
13. Safizadeh, M.R., Wagner, A., Evaluation of Radiant Ceiling Heating Systems for Renovated Buildings based on Thermal Comfort Criteria.
14. Pastore, L., Andersen, M. Comfort, climatic background and adaptation time: first insights from a post-occupancy evaluation in mulicultural workplaces
15. Mino-Rodriguez, I., Korolija, I., Altamirano, H. Thermal comfort in dwellings in the subtropical highlands - Case study in the Ecuadorian Andes.
16. Pallubinsky, H., Dautzenberg, B., Phielix, E., van Baak, M., Schrauwen, P., van Marken Lichtenbelt, W. Can regular exposure to elevated indoor temperature positively affect metabolism in overweight elderly men?
17. Nicol, F. Humphreys, M. Room temperature during sleep.
18. Zhang, N., Cao ,B. Zhu, Y. A research on het effects of indoor environment on sleep quality.
19. Gupta, R., Howard, A. A real-world empirical investigation of indoor environment and workplace productivity in a naturally ventilated office environment.

Remaining literature

Boerstra, A. C. (2016). Personal control over indoor climate in offices: impact on comfort, health and productivity.

The book of abstract and all conference papers can be downloaded from the conference website: http://windsorconference.com/

Comparative performance analysis of floor heating systems

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From a practical point of view the intermittent operation of underfloor heating systems is challenging due to the heating-up times resulting from the heat capacity in the floor. That is why several floor heating systems have been analysed in a comparative simulation study. It has been observed that heating-up times highly depend on installation heights and structures of the floor heating systems. The study shows in particular that some of the available renovation systems react up to three times faster than standard system.

Introduction

This article deals with the comparison of the heating-up times of four different floor heating systems: a standard wet system and three renovation systems with lower installation height. The renovation systems are the wet system K and two dry systems C and T. The dry-system T is characterized by a special heat conduction plate and the system C by the absence of an insulation layer. By using a transient coupled CFD simulation, the processes of heat conduction, heat radiation as well as the convective heat transport due to the air- and water flows are calculated.

The four systems show a different dynamic of the heating-up times. **Table 1** gives an overview about the layers of the four systems.

Methodologies and boundary conditions

Figure 1 shows the layer of the floor heating system by the example of the T dry system. One can see very well, how the heating pipes are surrounded by the heat

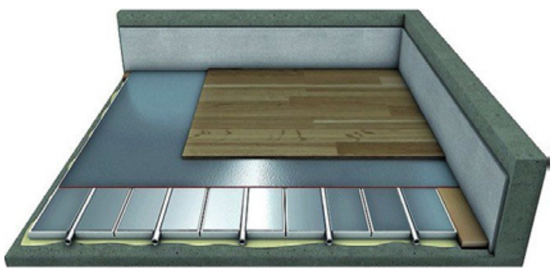


Figure 1. floor heating system T with heat conduction plates; reference: www.bba-online.de.

conduction plates. This heat conduction plates with a thickness of 0.25 mm are modelled fully three dimensional in the simulation model.

The four different systems are simulated in a test cabin made of 200 mm thick aerated concrete walls with a base area of 3 m x 3 m and an interior height of 2.75 m without openings, see **Figure 2**. Related to the floor area of 9 m2 a laying distance between the pipes of 150 mm leads to a pipe length of about 57.7 m and a laying distance of 125 mm results in a pipe length of 69.2 m.

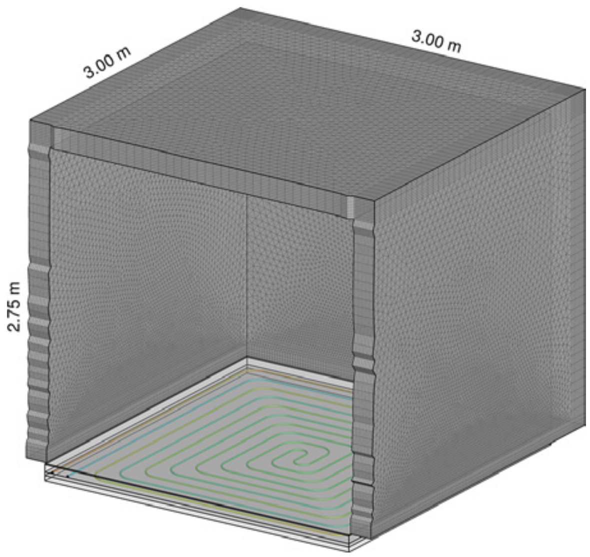


Figure 2. Geometry of the test cabin and meshing of the wall layers and laying patterns of the floor heating.

Transient, coupled simulations of the test cabin, underfloor heating system, water flow and room air flow are done for all four systems. For the evaluation, the surface temperatures and their local distribution as well as the water temperatures are evaluated in detail as a step response when switching on the underfloor heating system. Furthermore, the enthalpy flows between the water inlet and outlet and the (convective and radiative) heat flows from the floor are evaluated.

The numerical model considers the following aspects:

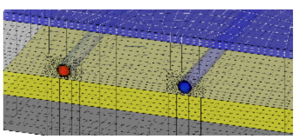
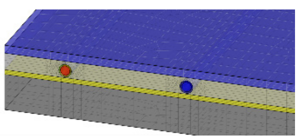
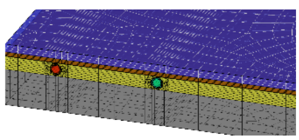
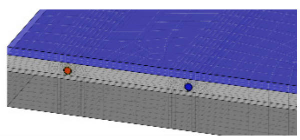
- three-dimensional non-isothermal water flow inside the pipes
- three-dimensional thermal conduction within the inner walls of the pipes as well as within all other layers in the respective floor structure
- three-dimensional heat conduction within the side walls of aerated concrete
- non-isothermal turbulent simulation of the air flow in the test cabin taking into account the radiation heat exchange within the test cabin

Results and Conclusion

The initial condition is a uniform temperature of all zones of 15 °C at the start time and a constant fluid in the test cabin as well as in the floor heating tube.

For the water inlet the mass flow rate into the heating pipes is set to 0.025 kg/s with a supply temperature of

Table 1. Layer of the floor heating systems from top down.

Wet system STANDARD	**Wet system K-**	**Dry system T - Figure 1**	**Dry system C**
Tiles, 10 mm	Tiles, 10 mm	Tiles, 10 mm	Tiles, 10 mm
Heating screed, 65 mm Heating pipe, 17x2 mm	Heating screed, 21 mm Heating pipe, 16x2 mm	Load distribution, 5 mm, λ = 0.2 W/(mK) Heat conduction plate, aluminium, 0.25 mm heating pipe, 14x2 mm	Heating screed, 21 mm Heating pipe, 10x1 mm
Insulation material, 30 mm, λ = 0.04 W/(mK)	Insulation material, 6 mm, λ = 0.04 W/(mK)	Insulation material, 17 mm, λ = 0.04 W/(mK)	No insolation material
Screed 45 mm	Screed 45 mm	Screed 45 mm	Screed 45 mm
			

35 °C. There is no heat loss assumed below the lower screed layer and on all sides of the floor structure. The calculations are done over a period of six hours of simulated real time. This period is chosen to ensure that in each of the four systems the desired mean surface temperature of the floor area of 24 °C is reached. The calculated flow velocities are less than 0.1 m/s in the tubes.

Figure 3, on the left in the upper part, shows the mean surface temperature profiles of the four different systems. The right side represents the corresponding profiles of the water return temperatures. In addition, the total thermal heat flows (convection and radiation) emitted by the respective floor as well as the resulting enthalpy fluxes transferred from the water to the respective floor structure are shown in the diagrams in the lower part of **Figure 3**.

The different dynamics of all four investigated systems can be clearly seen from the diagrams. Due to the much larger thermal mass of the heating screed, the STANDARD system has the biggest inertia, which results in a slower heating of the tiles and thus also a slower increase in the heat dissipation of the floor heating as a whole. The K system is more dynamic than C due to its insulating layer preventing heat to be transferred into the building structure rather than to the room. Due to the insulating layer, the heat flow into the screed below it is significantly lower than in the C-system. This is also shown by the overall higher

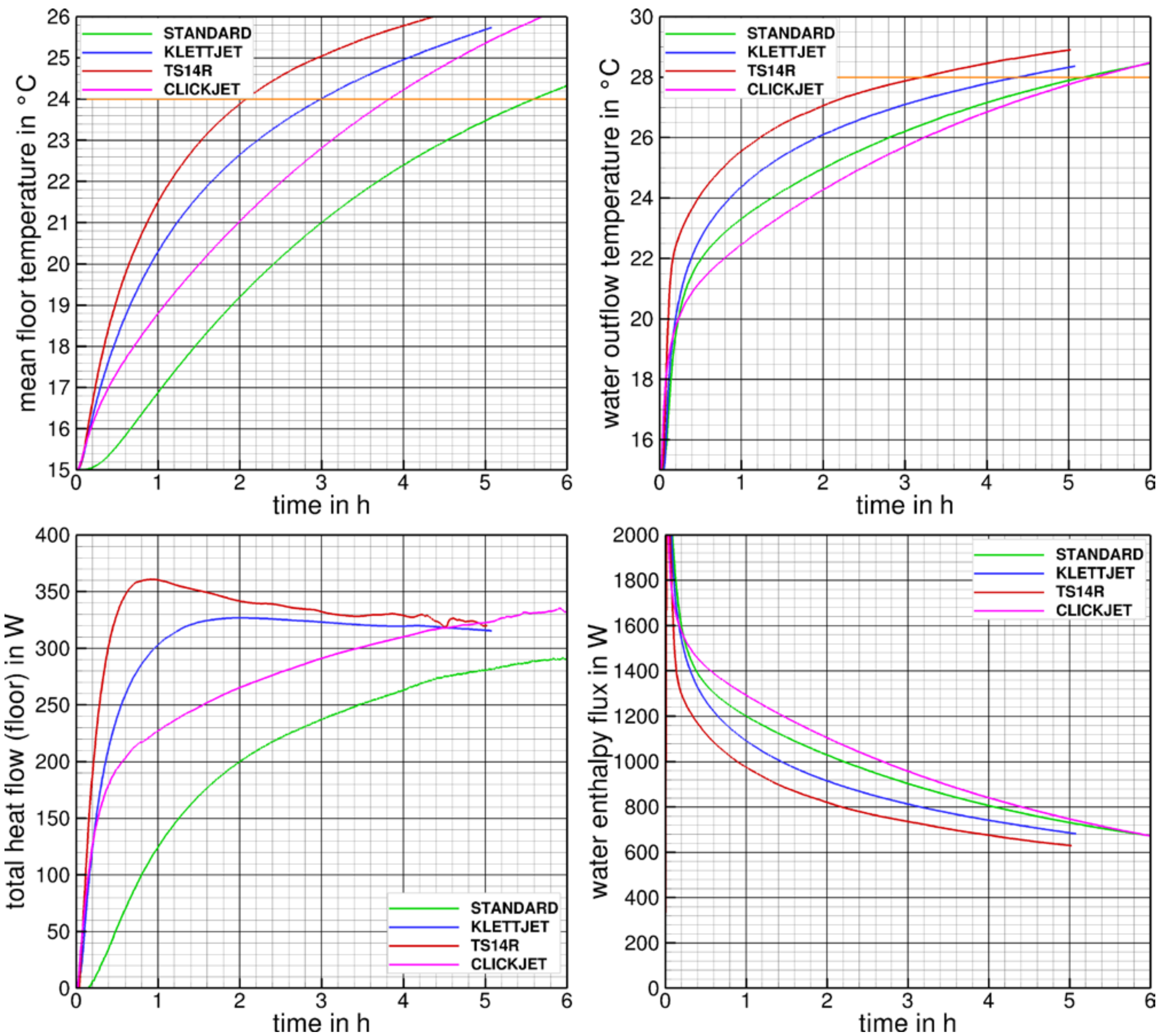


Figure 3. Step responses; from top left to bottom right: time profile of medium surface temperatures of the floor, time profile of mean return temperatures of the water, time profile of total heat flows of the floor, time profile of resulting enthalpy fluxes of the water; in each case for all four systems.

enthalpy flux which C-system's water gives to the surrounding floor layers (see **Figure 3**, bottom right). In this case, however, a higher heat flow through the tube walls occurs due to the smaller internal diameter of the tube and the associated higher velocity of the water. The good thermal insulation downwards as well as the very good heat distribution upwards over the heat conducting plates lead to a very high dynamic in the system T. The required average floor temperature is reached three times faster than with the system STANDARD. The T-system has been identified as a fast reacting underfloor heating system where the highest overall heat output of the floor is observed with the lowest enthalpy flux of the water during the heating phase. The energy transfer from the water to the chamber is therefore the fastest in this system.

The described facts can also be found in the representation of the temperature distributions of the different configurations, see **Figure 4**. If more energy has to be distributed in the floor, the system becomes slower.

If a parquet floor is modelled instead of the floor tiles, all systems react much slower due to the lower heat conduction of the wood layer. The differences between

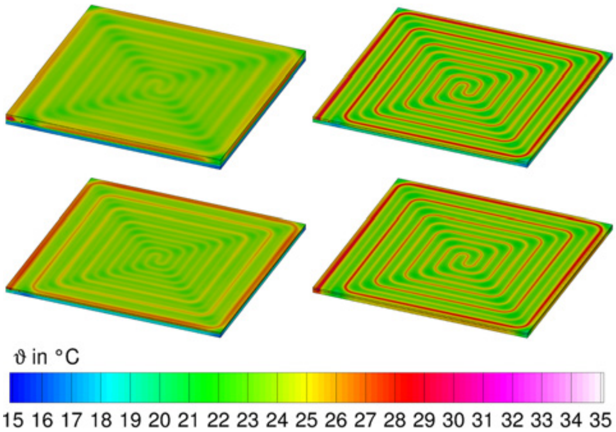


Figure 4. Surface temperatures of the whole underfloor heating system, after reaching a mean surface temperature of 24 °C, view from above; from top left to bottom right: the STANDARD-system and the systems K, T, C.

the floor heating systems analysed are smaller. However, this wooden surface layer leads to an equalization of the surface temperatures. The ripple of the temperature profiles is significantly lower in all four systems than in the case of the floor construction with tiles. ■

Industrial Ventilation: Global Perspectives

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The author will examine innovative scientific and engineering opportunities in the industrial ventilation field from a global perspective. Key factors such as low carbon economy and global competiveness have placed a new requirement on the proper engineering design of advanced industrial ventilation systems. Plans for the preparation of a revised Industrial Ventilation Design Guidebook (2021) will be discussed*.

Keywords: ventilation, Cleantech, Industry 4.0, Artificial Intelligence, contaminant control

*This article is an invitation to any REHVA researcher/expert/engineer/practitioner interested to contribute to any specific section of the revised DGB to contact Howard Goodfellow indicating the areas of interest. Contact quickly, as the Chapter leaders have already been selected by the Co-Editors but we need to make sure that we include the best science and best practices for industrial ventilation from the global community. We are also looking for reviewers for specific areas.

Driving Forces Today for Industrial Sectors

The manufacturing and processing industries are facing many challenges today. The fourth industrial revolution (Industrial 4.0) is happening at an accelerated rate and many companies are embracing disruptive technologies. This technology is an extension of the automation field which has seen the use of largely automatic equipment, including robots in a system of manufacturing or other production processes. Successful companies must adapt quickly, and new technical skills are required to implement this revolution. Many companies do not have technical personnel to implement these technological changes. Skills include Artificial Intelligence (AI) leaders, researchers, technologists, data scientists, engineers, etc. All of these innovative changes have a major impact on the proper design of industrial ventilation systems for the specific processes. There is an urgent need for a simple holistic model to provide technical guidance for implementation of Industrial 4.0. A proposed framework for a Smart Cleantech Model follows.

Smart Cleantech Model (SCM)

Cleantech is a general term used to describe products, processes or services that reduce waste and require as few non-renewable resources as possible. The goal is to develop a simple generic software platform for a wide range of industries to improve global competitiveness. This needs to be a multi-disciplinary approach (ventilation, sensors, AI) in a lab environment. This approach would require the integration of best practices for modeling, sensors, big data, and optimization (AI, deep learning). **Figure 1** identifies the framework for what SCM would look like for air (similar structures for the Cleantech model could be developed for water and solid waste).

A component of this model would be a SMARTVENT model for industrial ventilation which would be developed for manufacturing and processing plants.

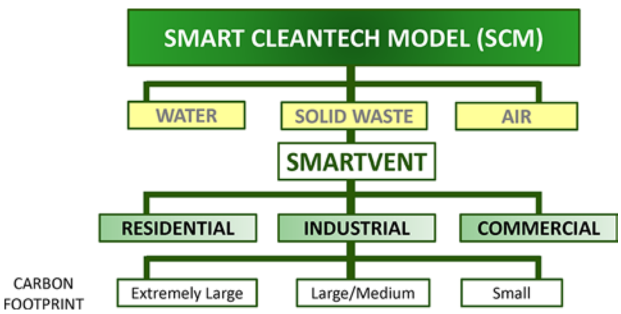


Figure 1. Smart Cleantech Model (SCM).

Industrial Ventilation DGB (2001)

In 2001, a scientific textbook edited by Howard D. Goodfellow and Esko Tahti was published by Academic Press. The **Industrial Ventilation Design Guidebook** addressed the design of air technology systems for the control of contaminants in industrial workplaces such as factories and manufacturing plants. It covered the basic theories and science behind the technical solutions for industrial air technology and included publication of new fundamental research and design equations contributed by more than 40 engineers and scientists from over 18 countries.

Readers were presented with scientific research and data for improving the indoor air quality in the workplace and reducing emissions to the outside environment. The Guidebook represented, for the first time, a single source for all current scientific information available on the subject of industrial ventilation and the more general area of industrial air technology. New Russian data was included that filled several gaps in the scientific literature.

- Presents technology for energy optimization and environmental benefits
- A collaborated effort from more than 60 ventilation experts throughout 18 countries
- Based on more than 50 million dollars of research and development focused on industrial ventilation
- Includes significant scientific contributions from leading ventilation experts in Russia
- Presents new innovations including a rigorous design methodology and target levels
- Contains extensive sections on design with modeling techniques
- Content is well organized and easily adaptable to computer applications

This comprehensive digest of scientific know-how gained its origin from the International Industrial Ventilation Conferences that were conceived by Professor Jim Smith and Howard Goodfellow from the University of Toronto (September 1985). **Figure 2** conveys the ventilation conferences held every three (3) years with the most recent conference being held in Finland in 2018. These specialized conferences have resulted in the development of a critical global mass of engineers and scientists working in the industrial ventilation field. Since the conference inception, there have been twelve international symposiums with more than 3000 attendees and over 1250 technical papers. The 13th International Industrial Ventilation Conference is now being planned for 2021 in North America.

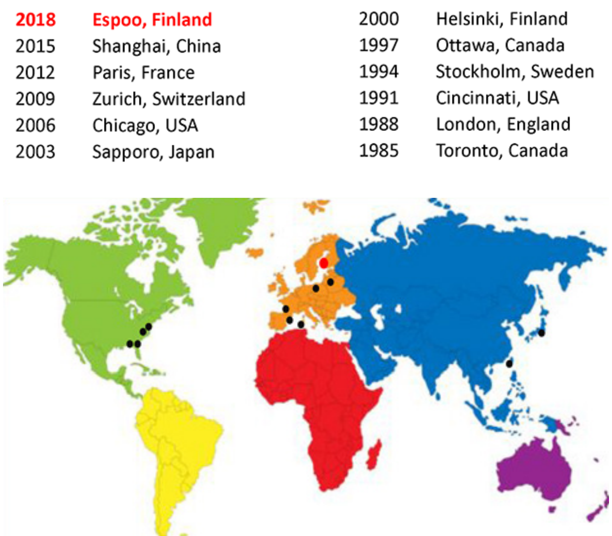


Figure 2. International Ventilation Conference Locations.

Revised Industrial Ventilation DGB (2021)

The proposed revised guide book covers the area of ventilation for contaminant control based on global research by world class researchers. This reference book is unique because it brings together global researchers and engineers to allow designers and engineers to solve complex ventilation problems using state-of-the-art design equations. Most of the equations and other scientific terms can be used in all ventilation and air conditioning fields, not only for ventilation contaminant control.

The recent awareness of climate change and a push by all industrial countries to embrace a low carbon economy has put a high pressure on industry to reduce their environmental footprint. European countries have taken a leadership role with the introduction of Industry *4.0* - automation plus sensors. For this to be implemented, engineers and scientists will be looking for a single reference source to find design equations and methodology to develop control algorithms for automation. Another key scientific component is the measurement of process parameters in real time using state-of-the-art sensors in the air and contaminant fields. These are specific areas that will be presented in depth for the first time in a detailed format based on global research in the sensor technology fields. Data will be presented both for leading edge sensor technology and well proven technology on a global basis.

The revised **Industrial Ventilation DGB (2021)** will be unique in the marketplace as it will present a single source for a holistic approach to industrial ventilation for contaminant control. Details will be presented for the four key steps:

Step 1: Design Methodology

Step 2: Design Equations

Step 3: Design Toolkits

Step 4: Specific Industrial Examples of Best Practice for Ten Major Sectors

The reasons for proposing this newly revised edition is because of the wealth of increase in new research technology in the broad field of ventilation for contaminant control on a global scale since the original Industrial Ventilation DGB was published in 2001. The preparation of the original book took ten years and major contributors from Europe and Russia where the level of science was the highest. Specific areas of advancement include: design methodology for ventilation systems for contaminant control, use of high-speed computers in modeling capabilities of air-flow and contaminant levels in both the workplace environment and the external environment, commercialization of the latest sensor technology such as lasers, etc., and the breakthrough of practical application of deep learning in the Artificial Intelligence (AI) field.

Our approach is to achieve harmonization of ventilation technologies on a global basis. Our extensive list of global experts will present for the first time a multi-sector cross cutting technology based on a holistic integrated approach of scientific research and engineering in the industrial ventilation field.

Figure 3 illustrates the major chapters being planned for the revised Industrial Ventilation DGB (2021). The revised book will have Professor Howard Goodfellow (University of Toronto) as Editor-in-Chief. The Co-Editors will be Professor Risto Kosonen (Aalto University, Finland) for *Volume I – Fundamentals* and Professor Yi Wang (Xi'an University, China) for *Volume II – Engineering Design and Applications*.

New features of the book will be as follows:

- Major new innovative technologies from researchers in China (book will become truly global)
- Further validation of design methodology and target levels based on plant experience
- Integration of automation and sensors (Industry 4.0)
- Closer collaboration with engineering schools and end users and the design/consulting communities
- Focus on gaps in ventilation using search engines to ensure all recent developments and innovations are included
- A new and expanded section on sensors technology and methodology of selecting the best sensor for each unique application
- Section on modeling and its practical applications will be expanded based on recent advances in research
- A new chapter on Best Practices for specific industrial sectors. The initial edition will be based on 10 industrial sectors with a proposed template that can easily be updated in the future to include other industrial sectors. An outline for the template for Best Practice is presented below

The template for Industrial Sectors for the Chapter on "*Best Practices*" for Industrial Ventilation for

Contaminant Control – Industry Specific Sectors for selected industrial sectors includes:

- Overview – Role of Ventilation
- Design Methodology
- Design Equations
- Design Toolkits
- Case Studies – Best Practice
- Future Challenges /Opportunities
- Selected Bibliography

Table 1 illustrates the features and benefits of the revised Industrial Ventilation DGB (2021).

The professional audience faces many issues. The first is that the literature (research and engineering) is highly fragmented in the research world (no specific home and often in different disciplines in different countries). The proposed book will provide a single source for relevant research and engineering in the industrial ventilation for contaminant control field.

Table 1. Industrial Ventilation DGB (2021) – Features/Benefits.

FEATURES	BENEFITS
Systematic Holistic Approach to Design with new section on best practices for ten selected industries	Accelerate implementation of best practice for end users
Global team of researchers and engineers as contributors	Single source of all recent research and best practice for industrial end users. Benefit for training of future researchers, designers and engineers to use IOT to achieve energy efficiencies, cleantech, climate change, etc.
Innovative state-of-the-art development of sensors, modeling, deep learning system performance evaluations, hyper linked equations	Provide key technical inputs required for challenges of low carbon economy and industrial 4.0

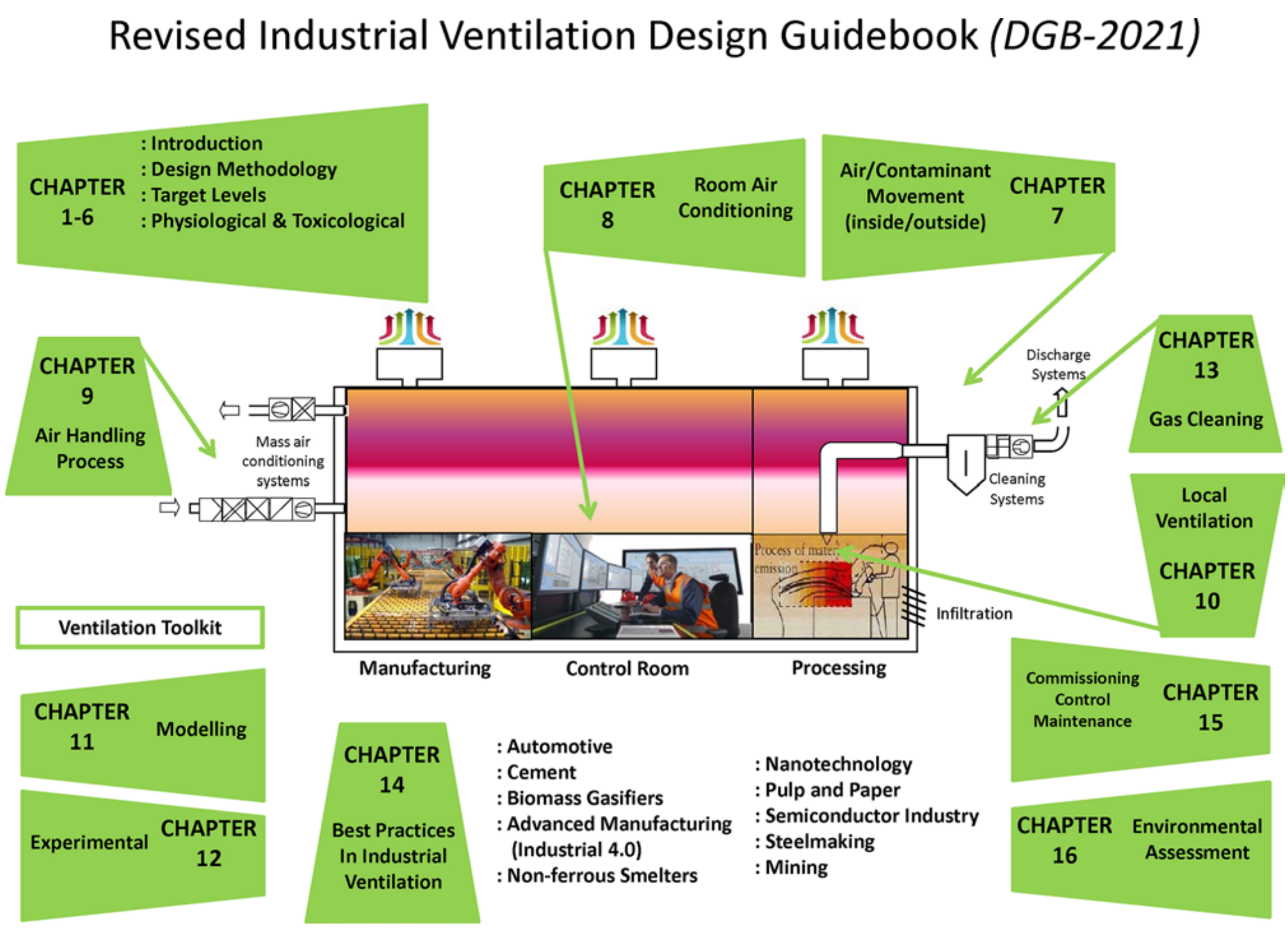


Figure 3. Outline of DGB (2021).

A second issue is that many of the text books, reference books and engineering books in this field have not been updated for a couple of decades or so, and do not reflect state-of-the-art for ventilation technology today and do not include the significant innovations in design criteria, modeling, sensors, AI (deep learning), etc., that are available to meet the new challenges of sustainability and a low carbon economy. The proposed book will focus on these recent developments.

The target audience will be at two levels and for a multi-sector industrial approach for processing plants and manufacturing. The proposed two levels for this revised DGB will be to bring researchers, engineers (both design and plants) and scientists to develop a fundamental scientific understanding of ventilation and to provide trained engineers to implement this state-of-the-art ventilation technology on a global basis. It is envisaged that the revised Industrial Ventilation DGB can be used as a core text book in an academic setting for mechanical engineers and process engineers. It is envisaged that it can be used as a background for specific industry based 1–5 day workshops and for plant and process engineers looking for a design methodology, sensors and control algorithms for specific industrial operations to meet the challenging low carbon economy. The textbook will also be a valuable reference book for consulting engineers working in the design of air pollution and sustainability for their industrial clients (processing and manufacturing).

Future Directions and Opportunities

The science and technology of industrial ventilation is at a crossroads and key decisions need to be made to capitalize on the unbounded opportunities. Three key areas to be pursued are:

- Better communication (scientific and engineering community of ventilation and contaminant control)
- Develop a global collaborative community
- Embrace disruptive technologies (sensors, modeling, automation, AI, etc.)

In the area of better communications, it is important to recognize that there are many common areas of scientific research and engineering in the ventilation and contaminant control field. The goal is to develop a holistic approach for the science of ventilation. **Figure 4** illustrates many of the common areas of science and technology for the residential, commercial and industrial sectors.

The second area is to develop a global collaborative network in the ventilation technology field. This global network would include scientific research (academic, research institutes), professional associations (ASHRAE, REHVA, SHASE), international technical conferences, low carbon economy, disruptive technologies (Industrial 4.0, AI, sensors, etc.), scientific publications (revised Industrial Ventilation DGB (2021)). Success depends on a holistic, multi-disciplinary and a sustain-

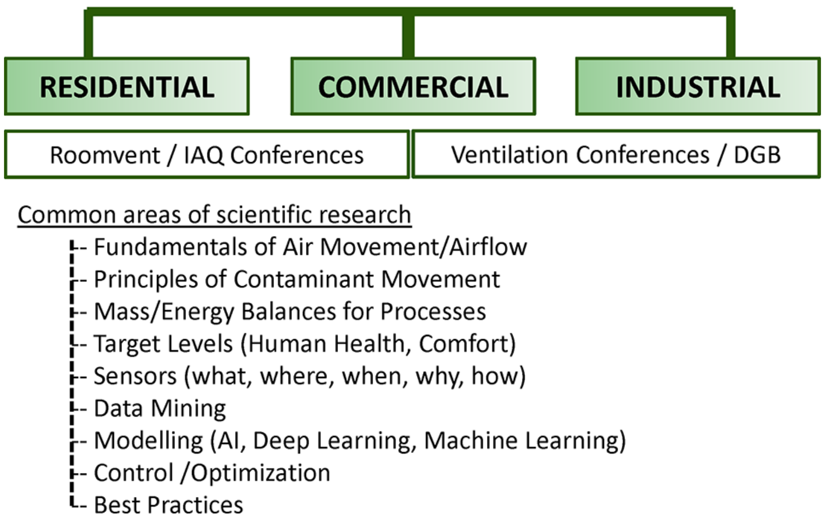


Figure 4. Science of Ventilation.

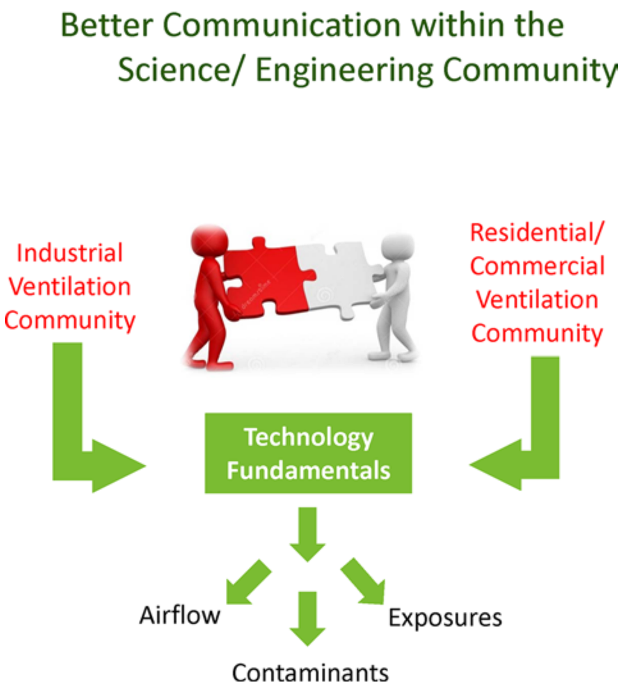


Figure 5. Communications Model.

able funding model. An excellent example of this goal to breakdown the silos is the leadership shown by ASHRAE President Professor Oleson in his August 2017 article in ASHRAE Journal entitled, ***Extending our Community***. The specific goals outlined in the report was the urgent need for the ventilation community to *"extend the global community"* and to *"extend the technological horizons."*

Figure 5 illustrates a model for better communications with the science and engineering community.

Disruptive technologies are happening at an accelerated rate and will have a major impact on the future directions of the science and technology of industrial ventilation. Disruptive technologies such as robotics, AI, models for low carbon economy, innovative sensors, etc., are impacting many sectors and researchers must embrace the cross transfer of these technologies. For example, innovative sensors are being developed that are wireless, non-invasive, cheap, remote, in-situ. Many of these sensors have wide applications for many different sectors (ie. autonomous vehicles) for advanced design of ventilation systems. ■

In summary, I urge all researchers and engineers in the industrial ventilation field to be:

BOLD

EMBRACE LEARNING

SUCCESS DEPENDS ON SIMPLICITY

The issue is never how to get new innovative thoughts into your mind ... but how to get old ones OUT.

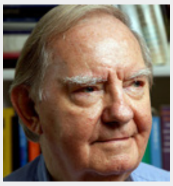
References

1. Goodfellow, H.D., Tahti, E., eds, "Industrial Ventilation Design Guidebook" Academic Press, 2001.
2. Goodfellow H.D., et al "Industrial Ventilation – A Review and Update" AIHAJ, March 1982, Volume 43, No.3, pg. 175-184.
3. Oleson, B.W., "Extending our Community" ASHRAE Journal, August 2017, pg. 14-21.

This article is part 2 of a series of articles on this case study, the discussed building is currently being realised. The first article has been published in RJ-2018-03 *

Earth, Wind & Fire: The Evolution of an Innovation (2)

– 'Fire': Natural ventilation and energy using the solar chimney



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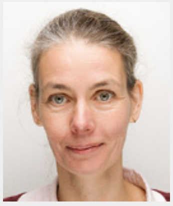

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A solar chimney is a building element that really appeals to the imagination that has now found a footing in the Netherlands. A search for 'solar chimney' online produces countless hits, many of which describe small-scale applications for home ventilation in the tropics. However, systematic scientific research into the functioning and optimisation of solar chimneys for use in non-residential buildings in the Western European climate is scarce. The results of the Earth, Wind & Fire (EWF) research project have made it possible to design a feasible solar chimney for this market, involving a combination of energy performance (through 'solar energy harvesting'), functional performance (through 'natural extraction of ventilation air'), and architectural performance (through the design of 'a beautiful building'). The solar chimney is a perfect symbiosis of architecture and technology and can make a substantial contribution to an energy-neutral built environment.

* https://www.rehva.eu/publications-and-resources/rehva-journal/2018/032018/earth-wind-fire-the-evolution-of-an-innovation-1-earth-natural-ventilation-and-air-conditioning-using-the-climate-cascade.html

Introduction

The solar chimney is a dominant architectural element and a typical example of climate-responsive architecture. By using the sun as a driving force for the extraction of ventilation air, the solar chimney can make an essential contribution to natural air conditioning in buildings. However, of even more importance is the solar chimney's absorption of solar energy, both thermal and electric, that can be used to heat buildings, restore the thermal equilibrium in the soil (through TES systems) and power pumps and auxiliary fans. This can make an important contribution to achieving energy neutral buildings.

The design and performance of the innovative solar chimney for use in generic applications have been described at length (Bronsema, B., 2013/A, B, C). A team of designers faced the interesting challenge of developing the concept for a specific project, Hotel BREEZE Amsterdam, into a PVT hybrid solar chimney 3.0.

With the help of valued input from various design partners, a robust solar chimney was designed that carefully balances architectural, thermal, aerodynamic and energy performance.

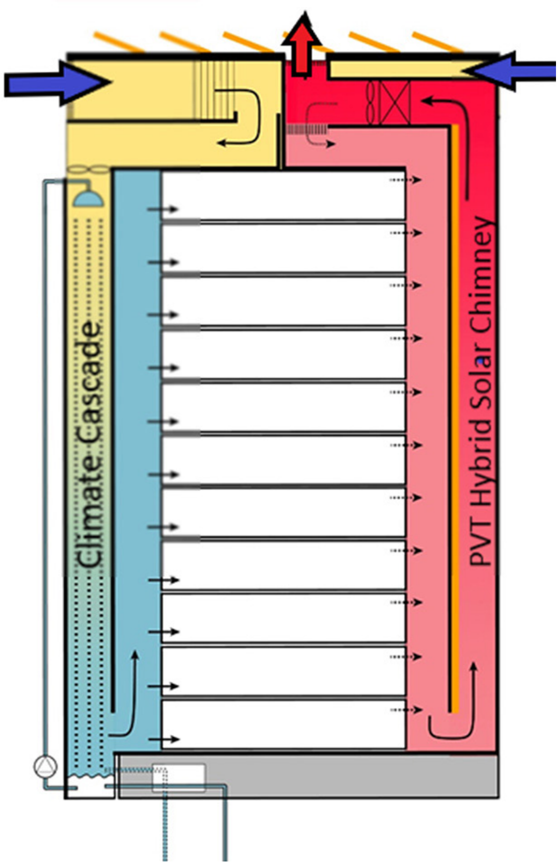


Figure 1. Natural Air Conditioning using PVT solar chimney 3.0.

An application was submitted for a BREEAM innovation credit for the PVT solar chimney 3.0 which describes the calculated performance requirements in detail. The experiences gained during the design, detailing and implementation phases will be meticulously recorded, and the thermal, aerodynamic and energy performance of the solar chimney will be monitored for the period of one year after completion of the project. The design documents will be continuously updated based on these experiences and progressive insights. The final design documents will then be made available for wide application of the solar chimney in the air-conditioning sector. In the meantime, the authors hope that the solar chimney will be implemented in various new-build or renovation projects in the short term, because '*Natural Air-conditioning: What are we waiting for?*' (Bronsema, B., *et al.*, 2018).

Design principles

In the Earth, Wind & Fire concept, the solar chimney is multifunctional:

1 extraction of ventilation air (aerodynamic performance)

2 solar energy harvesting (energy performance)

3 architectural value (architectural performance)

These performance requirements need to be prioritised in the design, whereby architecture (3) will often be dependent on (1) and (2).

The total ventilation rate for hotel rooms and general-purpose rooms is 25,000 $m^3.h^{-1}$. To reduce internal pressure loss, the air speed in the solar chimney will be ≈ 1.5 $m.s^{-1}$. To facilitate cleaning, the minimum depth has been set at 0.65 m, which means the width will be ≈ 7.0 m. The architect translated these design principles into a twin solar chimney of 2 x 3.5 m wide (see **Figures 2 and 3**). The energy performance of this solar chimney proved more than sufficient to heat the domestic hot water supply and restore the thermal equilibrium in the soil through the TES system.

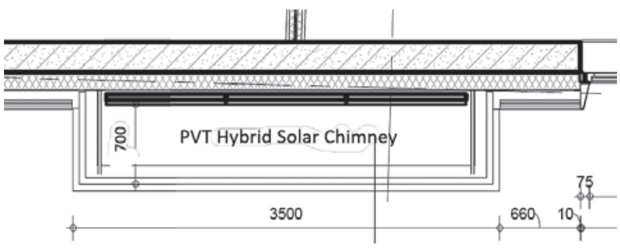


Figure 2. Detail of the PVT solar chimney in Hotel BREEZE Amsterdam (OZ Architects).

Generally speaking, it makes the most sense to optimise the design of a solar chimney to achieve the best energy performance. Because there is little pressure loss in the exhaust system, there is little to be gained by saving on fan energy. However, solar energy could contribute substantially to heating the building. In principle, the energy performance of the system can be increased or decreased, whereby the width of the solar chimney for a given height and chimney type will be the key design variable. A consequence is that the integration of the solar chimney in a wall may conflict with the architecture of the building.

Hotel Breeze Amsterdam's solar chimney

Figure 3 displays the sunny side of the hotel with the twin solar chimney in the south-west wall. The black areas are the building-integrated PV panels. Each solar chimney is 3500 mm wide and 650 mm deep. The front and side faces are glazed. The total height is ≈ 33 m and the total gross surface area on the south-west faced side is ≈ 230 m². The combined gross surface area of the south-east and north-west faced side is ≈ 42.5 m². The net glazed surface area was calculated with a reduction factor (R) of 0.95 of the gross surface areas

Hotel BREEZE Amsterdam, Aeon Plaza Hotels, OZ Architecten en Dutch Green Company

Figure 3. Twin Solar Chimney – NWA Architects /OZ Architects.

to take the account of structural elements that obscure incident solar radiation.

Materialisation

Glass curtain wall

The most important selection criteria for the glass curtain wall were:

- the highest possible g-value for maximum transmission of the incident solar radiation to the absorber
- the lowest possible U-value to reduce heat loss to the outside air
- maximum transparency of the glass wall through application of structural glazing without window post
- of linear thermal bridges

In the test setup of the Earth, Wind & Fire research project (Bronsema, B. 2013) the glass type SGG Planitherm Solar 4/15/4 argon was used. This glass is no longer obtainable as of 2017 and therefore the best available equivalent glass type SGG Eclaz 10-15-6 (diamant-argon/air-eclaz planiclear) will be used with physical properties of

- g = 0.71 [-]
- U = 1.1 $[W.m^{-2}.K^{-1}]$

The glass wall is constructed using structural glazing without window posts.

The backwall

Dynamic simulations have demonstrated that a solar chimney fitted with a thermally light, low-accumulating backwall will display better energy performance than a chimney with a thermally heavy backwall (Bronsema, B., 2013/A). The backwall of the solar chimney in Hotel BREEZE Amsterdam is constructed of light PV panels mounted on an insulation layer that are not affected by heat accumulation.

Absorber

The test setup of the Earth, Wind & Fire research project used Mirotherm absorber, which is a 0.5 mm thick anodised aluminium plate with a spectrally selective coating and an emission coefficient of ≈ 0.05. To increase exergetic performance, the absorbers in the twin solar chimney in Hotel BREEZE were attached to PV panels. The emission coefficient of these panels was considerably higher (≈ 0.87) than that of the spectrally selective absorber. The consequence was that the temperature of the glass wall was higher and there was more heat loss to the outside air. However, calculations reveal that this effect is minor, primarily due to the low U-value of the glass curtain wall.

PV panels

The absorber is constructed of 98 PV panels of the type Astronergy 300Wp mono Full Black, with additional power optimisers (brand: SMA/TIGO). This panel was selected for its black colour and the availability of an attestation of equivalence, which was required for the Energy Performance calculation. The module efficiency of these panels is 18.34%.

Insulation

Insulation with an $R_c \geq 5,0$ $[m^2.K^{-1}.W^{-1}]$ will be used.

Glass coating

The application of an anti-corrosive and dirt-repellent coating can significantly enhance the performance of a solar chimney and reduce the amount of cleaning needed. One such coating is the Vindico PV+ especially developed for PV panels (http://www.vindico.info). This coating is anti-reflective, which also helps to improve energy performance. The manufacturer claims that using Vindico PV+ increases light transmission by up to 5%. The positive influence of this coating on the g-value (in accordance with EN 410) is not known.

This article is part 2 of a series of articles on this case study, the discussed building is currently being realised. The first article has been published in REHVA JOURNAL 3/2018

HOW TO SCAN A QR CODE

Once you have a QR Code reader installed on your smartphone, you're ready to scan your first QR Code. Doing so is very easy. Just follow these simple steps.

1. Open the QR Code reader on your phone.

2. Hold your device over a QR Code so that it's clearly visible within your smartphone's screen.

Inspection and maintenance

The solar chimney must be accessible for inspections and maintenance (including cleaning) of both the glass wall and the PV panels. This has been taken into account in the design.

Airtightness

The air exhaust volume rate in the solar chimney must not be significantly influenced by wind pressure and the inherent infiltration of outside air. The design using structural glazing is expected to make this infiltration negligible.

Thermal efficiency

The thermal efficiency of a solar chimney is defined as the ratio between the net amount of heat extracted by the airflow divided by the incident solar radiation. The formula is as follows (Bronsema, B. 2013/A):

$$\eta_z = \frac{q_v.\rho.c(\theta_{uit} - \theta_{in})}{R.B.H.\Phi_{zon}} \quad (1)$$

Where

η_z	=	thermal efficiency of the solar chimney under reference conditions	
q_v	=	volumetric flow rate of the passing air	[$m^3.s^{-1}$]
ρ	=	air density	[$g.m^{-3}$]
c	=	specific heat of the air	[$J.g^{-1}.K^{-1}$]
θ_{out}	=	temperature of the outgoing air	[°C]
θ_{in}	=	temperature of the incoming air	[°C]
B	=	chimney width	[m]
H	=	chimney height	[m]
Φ_{sun}	=	solar radiant flux	[$W.m^{-2}$]
R	=	net reduction factor in relation to gross glass area	[-]

This formula can be reduced to:

$$\eta_z = g - \frac{U^*_{gl}(\theta_{gl} - \theta_e)}{\Phi_{zon}} - \frac{U^*_w.p.(\theta_w - \theta_a)}{\Phi_{zon}} \quad (2)$$

Where

g	=	g-value of the glass	[-]
U^*_{gl}	=	heat transfer coefficient of the glass surface → outside air	[$W.m^{-2}.K^{-1}$]
U^*_w	=	heat transfer coefficient of the wall surface → inside air	[$W.m^{-2}.K^{-1}$]
θ_{gl}	=	glass temperature	[°C]
θ_e	=	outside temperature	[°C]
θ_w	=	wall temperature	[°C]
θ_a	=	temperature behind the inner backwall	[°C]
p	=	total interior surface area/front surface area	[-]

This formula is very intuitive. The thermal efficiency of a solar chimney is determined by the three factors in the formula:

1. The g-value of the glass (easily the most important factor). The g-value of the chosen glass type is ≈ 0.71. This is also the maximum efficiency (assuming zero heat loss). The use of Vindico+ could lead to an increase of ≈ 5%, although this is somewhat speculative.

2. The heat loss to the outside air, determined by the U-value of the glass and the difference between the glass temperature and the outside temperature, which is the next highest heat loss factor.

3. The heat loss through the inner backwall, determined by the U-value of the backwall, the depth of the solar chimney and the difference between the wall temperature and temperature of the air behind it. This is the lowest heat loss factor thanks to the use of high-quality insulation with a low U-value.

The wall and glass temperatures in a solar chimney are interrelated functions of the radiation and convection heat transfer coefficients, which are in turn functions of the geometric ratios, air speed and the solar radiant flux.

Dynamic simulations demonstrate that an annual efficiency of 55–60% is achievable. An annual thermal efficiency of 60% was assumed based on the application of a good quality glass coating.

Efficiency of the hybrid PVT solar chimney

The absorber consists of PV panels, which means that part of the incident solar radiation is converted into electrical energy, to the detriment of the thermal efficiency. Formula 2 then becomes:

$$\eta_{z,} = g - \frac{U^*_{gl}(\theta_{gl} - \theta_e)}{\Phi_{zon}} - \frac{U^*_w.p.(\theta_w - \theta_a)}{\Phi_{zon}} - g.\eta_{pv} \quad (3)$$

Where

η_{pv} = PV panel efficiency

The reduction of the thermal efficiency leads to a reduction in heat output and thermal draught. However, the reduction of the low-grade heat output is compensated by the high-grade energy output of the PV panels, which will increase the exergetic efficiency of the solar chimney. The reduction of thermal draught can be compensated by an auxiliary fan.

Points of concern regarding the thermal properties of this concept are:

- The radiation and heat transfer ratios in the solar chimney are changed as a result of other properties of the absorber, resulting in 1.5–2% more heat loss.
- Because part of the solar radiation is reflected onto the glass wall, the effective efficiency of the PV panels is reduced by a factor g. For the selected Astronergy panels with a module efficiency of 18.34%, this means a reduction of up to (0.71*18.34) = 13%

The temperature in a solar chimney under the influence of incident solar radiation is higher than the outside temperature, which decreases the efficiency of the PV panels. For a temperature of 30°C and a temperature coefficient of –0.416%.K^{-1}, this amounts to a reduction of ≈ 2.0% in relation to the reference temperature of 25°C.

A thermal efficiency of 50% was assumed for the subsequent calculations.

Dynamic model

The Earth, Wind & Fire research project used the ESP-r dynamic simulation model (Gontikaki, *et al.*, 2010) to study the dynamic behaviour and estimate the annual energy performance of the solar chimney. This model was developed at TU Eindhoven and can be used by designers to analyse complex relationships between the inside and outside climate of a building based on architecture, building mass, air currents and climate systems (including the control system). It is a flexible and powerful tool and ideal for simulating innovative technologies.

Practical calculation model

In the conceptual phase, it is the architect who lays the foundation for the successful architectural integration of a solar chimney in a building. A user-friendly calculation model was designed for the purposes of this intuitive and interactive phase of the design that can be used to visualise different architectural variants and their energetic consequences with a click of the mouse (Bokel, R., 2011).

Energy performance

PV electricity

The estimated annual yield of the PV panels in the twin solar chimney is about 18,000 kWh (see **Table 1**). This assumes the specific monthly solar radiation level applied in NEN 5060:2008. The coverage of the PV panels is relatively low. In principle, better coverage could be achieved by optimising the width of the

Table 1. Energy yield of PV panels.

PV performance								
Month	Zuid							
	kWh.m^2.a^{-1}	opp. m^2	filling level	g-value	R-value	efficiency%	kWh.a^{-1}	kWh.a^{-1cum}
jan	41,1	230	0,7	0,75	0,95	18,34 %	860	860
feb	44,6	230	0,7	0,75	0,95	18,34 %	933	1793
mrch	61,1	230	0,7	0,75	0,95	18,34 %	1 278	3071
apr	101,3	230	0,7	0,75	0,95	18,34 %	2 119	5190
may	101,2	230	0,7	0,75	0,95	18,34 %	2 117	7307
june	90,3	230	0,7	0,75	0,95	18,34 %	1 889	9196
july	90,3	230	0,7	0,75	0,95	18,34 %	1 889	11084
aug	101,3	230	0,7	0,75	0,95	18,34 %	2 119	13203
sept	82,4	230	0,7	0,75	0,95	18,34 %	1 724	14927
okt	73,7	230	0,7	0,75	0,95	18,34 %	1 542	16469
nov	39,8	230	0,7	0,75	0,95	18,34 %	833	17301
dec	35,3	230	0,7	0,75	0,95	18,34 %	738	18040
total	862,4						18 040	

solar chimney to match the size of the PV panels (1654 x 989 mm).

Thermal energy

The estimated annual thermal energy yield of the twin solar chimney is about 101,000 kWh (see **Table 2**). This assumes the specific monthly solar radiation level used in NEN 5060:2008 and an efficiency of 50%. **Table 2** reveals that the contribution of the side walls is limited (≈ 12.9%).

The heat harvested in the solar chimney has a low temperature level and hence a low exergetic value, which means direct use for HVAC and domestic hot water supply is limited. The following options are available for the optimum use of the low-grade heat:

- The energy yield during the heating season (from mid-October to mid-April) is ≈ 31.6% of the total yield. In principle, this heat can be used to heat the building and the domestic hot water supply directly or indirectly using heat pumps.
- The energy yield during the cooling season (mid-April to mid-October) is ≈ 68.4% of the total annual yield. In principle, this heat can be used to heat the domestic hot water supply directly or indirectly using heat pumps.
- Another important consumer of heat in the cooling season is the TES system, which needs to compensate for the heat used during the heating season and restore the thermal equilibrium in the ground.

Exergy performance

The temperature level of heat determines the quality of the energy and is expressed in the exergy value *Exq*. The exergy value of PV electricity is equal to the energy value: $Expv = W$

The exergy value of heat is calculated with the formula:

$$Exq = (1 - T_0/T) * Q$$

Where

T_0	=	ambient air temperature	[K]
T	=	temperature of the heat flow	[K]
Qth	=	quantity of heat	[W]

Under reference conditions (solar radiation of 400 W.m^{-2} and an outside temperature of 20°C; see below), the temperature of the extracted air above the solar chimney is ≈ 30°C. The exergy value of the hot air is only 3.3% at this temperature.

Figure 4 displays the cumulative annual energy yield of the solar chimney, subdivided into thermal energy, PV electricity and the exergetic value of the thermal energy.

Aerodynamic performance

The thermal draught is a function of the outside temperature and the average temperature in the solar chimney, which in turn is a function of the solar radiant flux, the chimney efficiency and the air flow rate. The principle of the EWF concept was that the thermal draught would be sufficient to compensate for the pressure loss of the air exhaust system, including the

Table 2. Thermal energy yield.

Month	Southwest					Southeast	Northwest	Total	Cum.	Exergy
	kWh.m^2.a^{-1}	surface m^2	R-value	effiency%	kWh.a^{-1}	kWh.a^{-1}	kWh.a^{-1}	kWh.a^{-1}	MWh.a^{-1}	kWh.a^{-1}
jan	41,1	230	0,95	50 %	3 643	305	90	4 038	4 038	133
feb	44,6	230	0,95	50 %	3 817	392	153	4 362	8 400	277
ma	61,1	230	0,95	50 %	5 867	534	282	6 683	15 083	498
apr	101,3	230	0,95	50 %	10 546	1 000	548	12 094	27 177	897
may	101,2	230	0,95	50 %	11 702	1 035	746	13 483	40 660	1342
june	90,3	230	0,95	50 %	11 364	969	824	13 157	53 817	1776
july	90,3	230	0,95	50 %	10 132	969	666	11 767	65 584	2164
aug	101,3	230	0,95	50 %	10 448	1 060	608	12 116	77 700	2564
sept	82,4	230	0,95	50 %	7 732	775	383	8 890	86 590	2857
oct	73,7	230	0,95	50 %	6 478	615	227	7 320	93 910	3099
nov	39,8	230	0,95	50 %	3 446	318	109	3 873	97 783	3227
dec	35,3	230	0,95	50 %	2 923	276	71	3 270	101 053	3335
total	862,4				88 098	8 248	4 707	101 053	101 053	3335

solar chimney itself (under reference conditions). The reference conditions are defined as follows (Bronsema, B., 2013):

- Outside temperature θ_e = 20 [°C]
- Radiant flux ϕ_{sun} = 400 [W.m^{-2}]

The reference radiant flux is the average daily radiation on sunny days during the summer months (even if less sunny days are included, the average daily radiant flux is still ≈ 350 W.m^{-2}).

Figure 5 reveals that the required thermal draught is only ≈ 6.6 Pa under the reference conditions (R). It would be virtually impossible and certainly not cost effective to design the exhaust system based on such low-pressure losses. The auxiliary fan could be used to create sufficient draught in these conditions.

Figure 5 also clearly reveals the influence of the outside temperature on the thermal draught, that can increase to > 40 Pa on cloudy days and > 50 Pa on sunny winter days if the outside temperature is low. The solar chimney

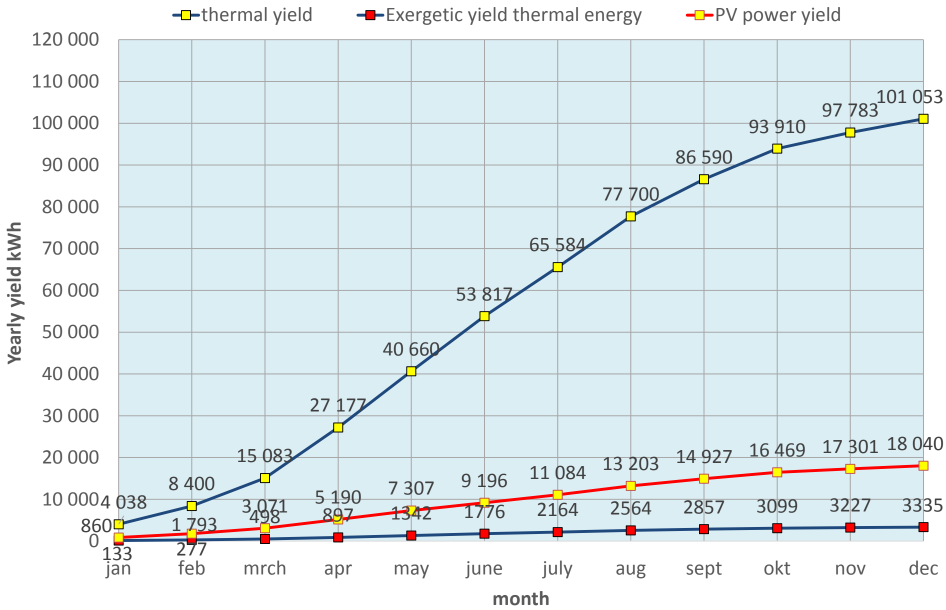


Figure 4. Cumulative annual yield of the PVT solar chimney.

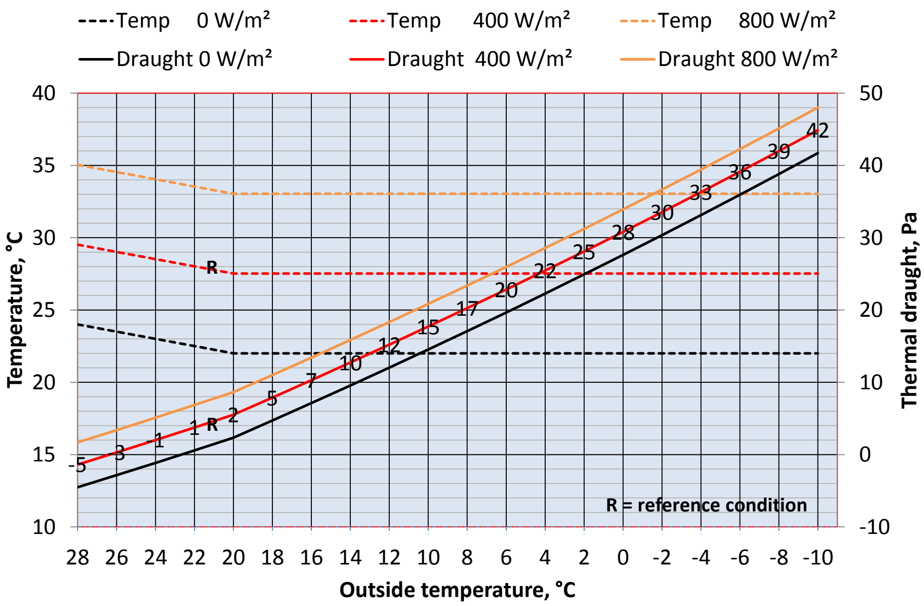


Figure 5. Outgoing air temperature and thermal draught as a function of the outside temperature and radiant flux (air flow rate of 25,000 m^3.h^{-1}).

functions as a thermal chimney in this situation and a flow control system is necessary to compensate for the variating thermal draught.

When the kitchen is in operation, the kitchen exhaust air, which has a flow rate of ≈ 7500 $m^3.h^{-1}$, is diverted away from the solar chimney. In this case, the air speed falls to ≈ 1.1 $m.s^{-1}$ and the air temperature can increase to ≈ 45°C. The calculated temperatures are well below the threshold of 80°C, when tempered glass must be applied.

To compensate for overheating caused by potential stagnation in the extraction system, a maximum temperature sensor will be installed at the top of the chimney which will restore the air flow.

Heat recovery

The principle of heat recovery is displayed in **Figure 6**. The heat extracted from the solar chimney serves as a heat source for a heat pump, which upgrades the heat and transfers it to the hotel's hot water supply for heating the building, domestic hot water and to restore the thermal equilibrium in the ground through the TES system. The cooled air is then extracted through the Ventec heat exchanger on the leeward side of the building (Bronsema, B., et al., 2018/C).

It will be an interesting challenge to optimise the system in combination with the domestic hot water storage capacity. To be energetically efficient, the heat pump will preferably operate under the highest possible source temperatures, in this case the hours of optimum sunshine and radiation intensity.

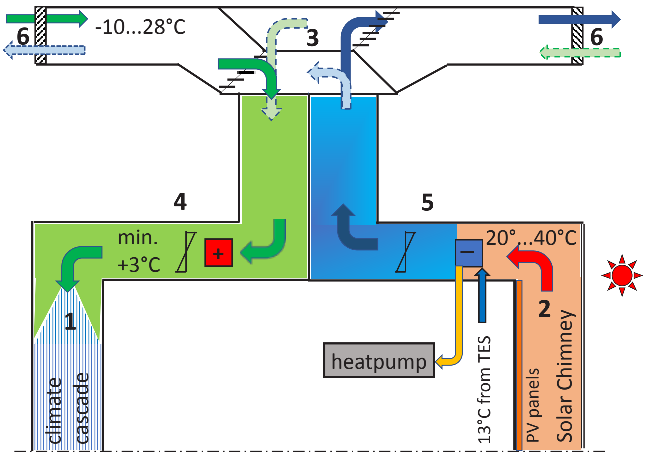


Figure 6. Principle design of air supply and extraction using the Ventec heat exchanger.

Exhaust fan

The rpm-controlled extraction fan will maintain the exhaust air flow rate at 25,000 $m^3.h^{-1}$, independent of the thermal draught of the solar chimney and the wind forces on the side wall.

The positive thermal draught of the solar chimney depends on the solar radiant flux and the outside temperature and can vary between –5 Pa and +50 Pa (see **Figure 4**).

The extent of the negative draught depends on the outside temperature θ_e and the simultaneous solar radiant flux Φ_{sun}. Assuming very extreme conditions, with an outside temperature of 35°C, a thunderstorm that practically blocks out all sunlight, and heating of ventilation air in the solar chimney reduced to zero (and if heat transmission through the glazing and water accumulation in the solar chimney are both negligible), the negative draught could increase to ≈ –10 Pa. ■

References

Bokel, Regina 2011. *Een gebruiksvriendelijk rekenmodel voor het initieel ontwerp van een zonneschoorsteen*. Technische Universiteit Delft - Faculteit Bouwkunde – Afdeling AE+ T.

Bronsema, B. 2013/A. *Earth, Wind & Fire – Natuurlijke Airconditioning*. PhD Thesis TU Delft. Uitgeverij Eburon Delft. ISBN 978 90 5972 762 5. TU Delft Repository https://tudelft.on.worldcat.org/oclc/845637529.

Bronsema, B. 2013/B Earth, Wind & Fire – Natural Airconditioning [1] Research objectives and Methods. Conference paper 11th REHVA world congress CLIMA 2013.

Bronsema, B. 2013/C *Earth, Wind & Fire – Natural Airconditioning [2]* Results of the research. Conference paper 11th REHVA world congress CLIMA 2013.

Bronsema, B. et al 2015. *Earth, Wind & Fire – Natural Air-conditioning*. Conference paper Healthy Buildings Europe 2015.

Bronsema, B. et al 2018. *Natural Air-conditioning: What are we waiting for?* REHVA Journal April 2018.

Gontikaki, M. en Houben, J. 2010. *Calibration & Validation Report of the ESP-r solar chimney model*. TU Eindhoven, faculty of Architecture Dept. Building Physics & Systems.

Latest updates of the "Clean Energy Package" policies that are influencing the building sector

The "Clean energy package" is bringing an important piece of European energy legislation and shapes European climate and energy legislation beyond 2020. REHVA is closely monitoring the progress of all policies that are relevant for the HVAC and building sector. In this article, you will find a summary of the key policy developments of the past months and some outlook in the upcoming policy developments, pointing out the main issues for HVAC professionals and manufacturers.

AUTHORS: ANITA DERJANECZ & REBEKA MARŠNJAK

REHVA has been actively advocating and extensively reporting about the 2nd recast of the EPBD directive until the revised document was approved by the European Parliament in May 2018. In parallel with the EPBD review however, EU policy makers were working on other important parts of the Clean Energy Package in the past months.

2nd recast of the Energy Performance of Buildings Directive (EPBD)

On the 19th of June 2018, the amending Directive 2018/844 [1] was published, with a transposition deadline in March 2020. One of the main novelties of the new revised directive is focusing on the development of **national renovation strategies** (article 4 of the Energy Efficiency Directive was moved to the article 2A of the EPBD and being considerably strengthened) to achieve an energy efficient and decarbonised European building stock by 2050. It also addresses healthy indoor climate conditions, fire safety and risks related to intense seismic activity. Member states have now 2 years to develop long-term strategies with a clear vision for 2030, 2040.

Member states shall also encourage that technical buildings systems are replaced or upgraded to high efficiency system as far is technically and economically feasible, which plays an important role in reducing costs and improving the IEQ in our buildings. Regarding the **inspections of heating, cooling and ventilation systems** (articles 14 and 15 define the change of the threshold for inspection of heating and ventilation system from 20 to 70 kW rated effective output), as well as provisions related to **Technical Building Systems** such as mandatory individual temperature room control, **mandatory installation of Building Automation & Control systems** by 2025 in large non-residential buildings.

A further important point of the revised directive is the introduction of the **voluntary smart readiness indicator (SRI)**, promoting digitalisation and smart technologies. The Commission is supposed to adopt a delegated act by 31 December 2018 establishing an optional common European Union scheme for rating the smart readiness of buildings covers features such as smart metering, building automation and control systems, self-regulating devices for indoor temperature, built-in home appliances, recharging points for electric vehicles, energy storage, etc.

By 2020 the Commission will conclude a **feasibility study on the inspection of stand-alone ventilation systems** linked with the optional building renovation passport complementary to Energy Performance Certificates (EPCs). DG Energy has launched a service tender for the study, REHVA is involved in one of the tendering submitted by BPIE, INIVE and other partners and will closely follow the study preparation.

Energy Efficiency Directive: provisional agreement is waiting for a final approval

To review the EED from a 2030 perspective, the Directive was amended in 2018 (the final text is not yet enforced). The main **energy efficiency targets** that EED brings is a non-binding 32,5 % EU headline for 2030, with a possible revision of this target in 2023. Article 7 on obligations of the MS to achieve their targets through developing an Energy Efficiency Obligation scheme (EEO) [2] and/or using alternative policy instruments (like energy certificates, minimum energy performance requirements) was strengthened and extended until 2050 with an effective **energy savings rate** at 0.8 % of the final energy consumption. The EP called for a 35% binging energy efficiency targets, and REHVA - alike several EU level stakeholders - has been advocating for them since the beginning. However, Member States refused accepting a binding target and managed to decrease the target after some difficult negotiation rounds.

Governance of the Energy Union

A major horizontal pillar of the Energy Union related legislation is the Regulation on the Governance of the Energy Union, which will amend several, governance related articles of 10 different directives and regulation related to energy and climate change. After a joint ENVI - ITRE Committee meeting endorsed the proposal, a provisional agreement [3] was reached with the Council on the common regulation on 28 June 2018. In the following steps the provisional agreement must be voted on the next EP plenary meeting (most probably in October 2018) and in a case of endorsement, it will be approved as final version for enforcement.

Energy labelling: a mandatory product database from 2019 affecting manufacturers and suppliers of HVAC equipment

The technological progress in product energy efficiency over the past years encouraged the definition of a new framework for energy labelling repealing the Directive 2010/30/EU [4] updating the previous labelling scale. The revised energy labelling framework introduces also a **product regulation database to be established by 2019.** The database will consist of a compliance part (only accessible to market surveillance authorities and the EC) and a public part. The main aim of this database is to support market surveillance activities of Member States and provide consumers with a tool and overview on the energy efficiency of appliances. After a product will be published, it will display the name/trademark and contact details of the supplier, model identifier, energy label together with energy efficiency class and other parameters (along with parameters of the product information sheet). **From 1 January 2019, suppliers must enter in the database all new products before placing them on the market**. They are required to provide the model identifier of all equivalent models already placed on the market as well as specific parts of the technical documentation (see Article 12.5), additional parts can be voluntarily uploaded. Suppliers must enter similar information in the database by 30 June 2019, for all equipment placed on the market between 1 August 2017 and 1 January 2019.

The EC is currently developing the **online database**. During the stakeholder meeting in spring 2017 the Commission was presenting the practical implementation aspects [5] of this database and how the direct interaction with an existing market surveillance authorities will be provided. In the new portal, all public data will be accessible without registration in a separate system for consumer imported from the password protected non-public database. The aim is to provide a One-Stop-Shop (the portal) containing all information related to a regulated product group, including hyperlinks to Eur-Lex, to standardization databases, etc.

Ecodesign and energy labelling: revised framework and new working plan to further increase the efficiency of energy-related products

Ecodesign and Energy Labelling improve the energy and resource efficiency of products and reduce emissions, waste and energy dependency. It is expected that by 2020, the Ecodesign regulation can deliver approximately €55 billion per year extra revenue for industry, wholesale and retail sectors. This year on 31 of May, the European Parliament had adopted a resolution on the implementation of the Ecodesign directive (2009/125/EC) (2017/2087 (UNI))[6].

The new Ecodesign Working Plan 2016-2019 [7] has the potential to deliver further energy savings by 2030 and it contributes to the circular economy by introducing a systematic focus on durability, reparability and recyclability when developing new Ecodesign measures, and by the in-depth assessment of products with the most savings potential. The new ErP includes solar panels and building automation and monitoring systems that are now being assessed under the 2016-2019 working plan. It is important to note that no Ecodesign measure will be proposed for Building Automated Control Systems, if it is considered that the energy saving potential in buildings can be better captured with a new EPBD and EED Directives.

Beside the new Ecodesign Working Plan the Commission has adopted concrete measures, such as guidelines [8] to improve product testing and compliance checking by Member States and new Ecodesign requirements for air heating and cooling products [9] to deliver substantial energy savings.

The Smart Readiness Indicator (SRI): a 2nd study will commence in autumn 2018

The revised EPBD Directive introduced the Smart Readiness Indicator that should rate the smart readiness of buildings, i.e. the capability of buildings to adapt their operation to the needs of the occupant, also optimizing energy efficiency and overall performance, and to adapt their operation in reaction to signals from the grid (energy flexibility). The smart readiness indicator should also raise awareness amongst building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and give confidence to occupants about the actual savings of those new enhanced functionalities.

DG ENER contracted an expert consortium led by VITO to develop the SRI methodology. The final report of the SRI study [10] was published in July 2018 proposing a multi-criteria assessment methodology for the SRI assessment listing serviced in 10 domains with different weighting. Annex A [11] consist of a Service Catalogue with an overview of all 52 smart ready services to be inspected. REHVA has been following the development of the study and had a meeting with DG ENER explaining to present REHVA's opinion about the methodology.

DG ENER launched a second call for tender [12] for a 2nd **study on "Support to the establishment of a common European scheme for rating the smart readiness of buildings"** to consolidate and revise the outputs of the first study, focus in the implementation of the scheme and develop an impact assessment. The study should lead a critical in-depth review of the developed methodology, including the definition and calculation methodology and give technical recommendations on possible updates on the technical scope of the SRI and on its technical framework, as proposed by the first technical study. The study shall also investigate the applicability of the SRI on a selection of reference buildings representative of the EU building stock. The expert consortium should work extensively with Member States and conduct the study based on their comments regarding the methodology, organisational scheme and implementation. It should also develop an operational and organisational design of the SRI scheme, i.e. how the scheme can be set up, run and monitored, including possible mechanisms for verification, market surveillance and compliance.

The work is supposed to start in October 2018 and will involve Member States in the consultations. The European Commission plans to have a delegated act and an implementing act by end of 2019 / early 2020 based on the 2 completed studies. REHVA closely follows the process and provides inputs to the work of the second study as well. The Policy officers in charge of the SRI studies will be a speaker at the REHVA Brussels Summit Conference on 13 November 2018 allowing the possibility to receive first-hand information about the latest updates and exchange views about the further steps. ■

References

Ecodesign and Labelling. Available at: https://www.eceee.org/ecodesign/process/

Ecodesign Working Plan 2016-2019. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/com_2016_773.en_.pdf

Smart Readiness Indicator for Buildings. Available at: https://smartreadinessindicator.eu/milestones-and-documents

Support for setting up a Smart Readiness Indicator for buildings and related impact assessment: Final report. Available at: https://smartreadinessindicator.eu/sites/smartreadinessindicator.eu/files/sri_1st_technical_study_-_final_report.pdf

European Commission: Putting energy efficiency first: consuming better, getting cleaner. Available at: http://europa.eu/rapid/press-release_MEMO-16-3986_en.htm

Guidelines accompanying Regulation (EU) 2016/2281. Available at: https://ec.europa.eu/energy/sites/ener/files/documents/guidelines_air_heating_products_-_final.pdf

European Commission-air heating and cooling products. Available at: https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products/air-heating-and-cooling-products

Buildings in the Clean Energy Package – a BPIE guide. Available at: http://bpie.eu/news/buildings-in-the-clean-energy-package-a-bpie-guide/

Links

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=EN

[2] https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/obligation-schemes-and-alternative-measures

[3] http://www.europarl.europa.eu/meetdocs/2014_2019/plmrep/COMMITTEES/CJ10/DV/2018/07-10/4-provisional-agreement-turmes-rivasi-governance-EN.pdf

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1369&from=FI

[5] http://www.energimyndigheten.se/globalassets/energieffektivisering_/jag-ar-saljare-eller-tillverkare/dokument/eprel---assumptions-v2.80.pdf

[6] http://www.europarl.europa.eu/sides/getDoc.do?type=TA&language=EN&reference=P8-TA-2018-0241

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016DC0773

[8] https://ec.europa.eu/energy/sites/ener/files/documents/guidelines_air_heating_products_-_final.pdf

[9] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2016.346.01.0001.01.ENG&toc=OJ:L:2016:346:TOC

[10] https://smartreadinessindicator.eu/sites/smartreadinessindicator.eu/files/sri_1st_technical_study_-_final_report.pdf

[11] https://smartreadinessindicator.eu/milestones-and-documents

[12] https://etendering.ted.europa.eu/cft/cft-display.html?cftId=3653

How to choose the right parameter for humidity control in HVAC

Most people working in the HVAC field are familiar with relative humidity (RH) as a parameter used to measure and control buildings. But RH is not always the best choice as a control parameter. In some cases there are options that will make the conditions more stable or the system commissioning easier. Let´s take a look at the different options.

Relative humidity

Relative humidity is treated as the default humidity measure in HVAC. It is the best choice for controlling office and other spaces where human comfort is the main purpose, RH is a quite good choice as a control parameter. It allows flexibility in the temperature settings without changing RH control settings, for instance allowing higher temperatures in the summertime and lower temperatures during the winter heating season. It is also directly related to human comfort and many biological processes such as mold growth. A drawback is that very tight temperature and humidity control is difficult to achieve as the temperature affects the relative humidity as well. Thus, two controls may start fighting each other causing oscillation in the control loops.

Dew point temperature

The Dew point temperature (Td) indicates at which temperature you will see the onset of condensation. A low dew point temperature indicates dry conditions and a high dew point indicates high humidity. The dew point cannot exceed the ambient temperature. When the dew point is the same as the ambient temperature, you have reached saturation and the RH is 100%. The advantage of using dew point in HVAC controls is that it is not affected by temperature changes. This is an advantage if you need really tight and stable control for both temperature and humidity. The control circuits are independent of each other, so changing the temperature does not change the dew point in the controlled space and vice versa. Dew point and temperature control is used in spaces with the highest requirements for stability, like labs, museums, and data centers.

Wet bulb temperature

The wet bulb temperature indicates the temperature to which a water surface can be cooled by evaporation. This cooling effect varies with the relative humidity of the ambient air. When the air is saturated with water there is no evaporation and no available cooling. The wet bulb temperature is used to control cooling towers which can give access to low-cost cooling especially in hot and dry climates. If the humidity is too high and the wet bulb temperature approaches the ambient temperature it does not make sense to run the cooling towers as the available cooling effect is too small.

Enthalpy

Enthalpy indicates how much energy needs to expended to get to the measured state from a reference state, usually dry air at 0°C. The most common unit is kJ/kg. If you know the enthalpy of return air and make up air, you can decide directly if you should re-condition return air or replace it with outdoor air. This is not immediately evident just from temperature measurements as the humidity of the air impacts the enthalpy more than the temperature. Enthalpy is thus the measure of choice when your target is to maximize energy savings.

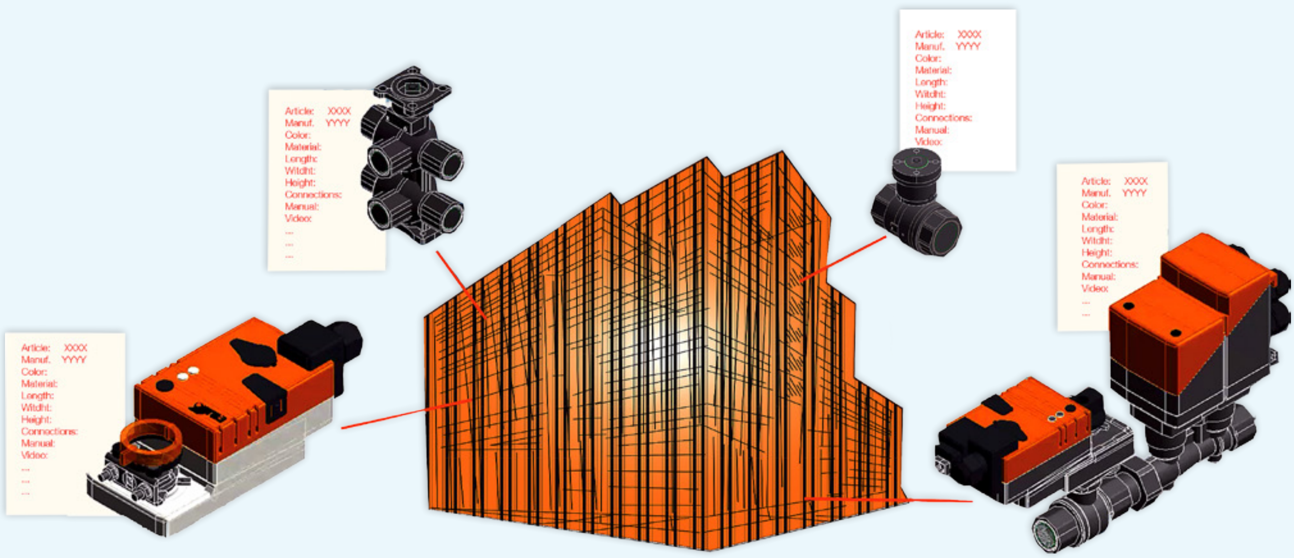
All of these humidity measures can be calculated from measured RH and temperature. You can do this in your control system, but many modern humidity transmitters can do the job for you. For instance, the Vaisala HMD62 duct humidity sensor allows you to select the desired humidity output in the field with a DIP-switch. Vaisala also offers a free of charge online humidity calculator https://www.vaisala.com/en/lp/humidity-calculator that makes parameter conversions easy. ■

BY LARS STORMBOM, SENIOR PRODUCT MANAGER AT VAISALA

World-leading valve and actuator solutions from Belimo implemented in BIM

Easier and more efficient planning

Humans spend around 90% of their lifetimes inside closed rooms, so a good room climate is important. Air quality in particular has a huge impact on our health and well-being. Air tight building shells may well be superior in terms of energy, but they prevent natural air exchange. However, they can be fully automated using appropriate ventilation systems and sensors.



Building Information Modeling (BIM) is the digital future of planning, construction, and management of buildings. It can already be seen in the directives for the EU procurement legislation. Since 2016, all 28 European states have been required to test and promote the use of BIM in the realisation of publically financed construction and infrastructure projects. The deciding advantage: all participants in a project – architects, engineers, building promoter etc. – access the same 3D model, share the same level of knowledge, and retain an overview of the complete project at all times.

As a globally active group for building automation, Belimo has recognised the significant benefits for planners and building promoter and has endorsed BIM. As a result and with immediate effect, all participants in a project in BIM now use only a small Belimo database for the selection of the 3D data model. They thus have full transparency for all Belimo product data and receive up-to-date information immediately and with an improved level of quality. Cost-intensive planning errors due to incorrect product dimensions and subsequent changes are effectively excluded through this planning method. Furthermore, safety is increased, particularly in building automation, because the finished building can already be virtually simulated in the draft phase.

A glance into the neighbouring countries of Great Britain, the Netherlands, Denmark, Finland, and Norway shows that the pioneering tool of BIM will continue to expand in the context of public construction projects. The sustainability, transparency, and efficiency of BIM has already been recognised and the use thereof even prescribed in law. For example, the British Government reports significant savings in public works contracts since 2012 and of a 66% completion rate within the defined budgets and deadlines as a result of the use of BIM. ■

More information: **www.belimo.eu**

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Send information of your event to Ms Chiara Girardi cg@rehva.eu

Events in 2018-2019

Exhibitions 2018

Nov 22-24	REFCOLD India 2018	Gandinagar, Gujarat, India	www.refcoldindia.com
Nov 26-29	HVAC R Expo	Dubai, UAE	www.hvacrexpodubai.com

Exhibitions 2019

Jan 14-16	AHR Expo	Atlanta, USA	www.ahrexpo.com
Feb 27 - Mar 1	WSED 2019	Wels, Austria	www.wsed.at/en
Feb 28 - Mar 2	ACREX 2019	Mumbai, India	www.acrex.in
Mar 5-7	Futurebuild	London, UK	www.futurebuild.co.uk
1-5 April	BET - Building Energy Technologies 2019	Berlin, Germany	

Conferences and seminars 2018

Nov 5-7	Retrofit Europe "SBE19 NL" Conference	Eindhoven, The Netherlands	
Nov 12-13	REHVA Brussels Summit 2018	Brussels, Belgium	
Nov 22-23	National Congress on Air-Quality	Madrid, Spain	

Conferences and seminars 2019

Feb 1-2	ACIEQ – Asian Conference of Indoor Environmental Quality	New Delhi, India	www.acieq2019.org
Feb 20-22	AiCARR 51st International Conference "The human dimension of building energy performance"	Venice, Italy	
Feb 27 - Mar 1	WSED 2019 - European Energy Efficiency Conference	Wels, Austria	https://bit.ly/2E9WiMS
May 26-29	CLIMA 2019	Bucharest, Romania	www.clima2019.org/congress/
Sep 2-4	Building Simulation 2019	Rome, Italy	www.buildingsimulation2019.org
Sep 5-7	IAQVEC 2019	Bari, Italy	www.iaqvec2019.org
Oct 2-5	ISK-SODEX 2019	Istanbul, Turkey	www.sodex.com.tr/en

The World Sustainable Energy Days

Clean. Competitive. Connected.

The World Sustainable Energy Days is one of Europe's largest annual conferences in the field of energy efficiency and renewable energy. It takes place each spring in Wels/Austria and features policies, technologies, innovation and market development in a unique combination of conferences and interactive events. In 2018, it brought together over 600 delegates from 66 countries from research, business and the public sector.

Energy efficiency and renewable energy are at the core of Europe's commitment to a clean energy transition that serves the needs of citizens, economic development and the environment. Achieving a smart, socially fair and sustainable energy system requires strong policies, competitive businesses and technology innovation. Mastering the digital transformation of energy and buildings will be crucial for creating a thriving economy and for the success of the global clean energy transition. The World Sustainable Energy Days 2019, which will take place from 27 February – 1 March 2019, connect people and empower them to embrace the necessary change.

Energy efficiency first: The European Energy Efficiency Conference

The 2019 edition of the **European Energy Efficiency Conference** comprises 6 conferences covering topics ranging from research to policy. Among these are the "Energy Efficiency Policy Conference" covering policy, markets and financing and the "Energy Efficiency Economy Workshop" addressing business models and innovative energy services. The "Innovation Workshops Energy and Buildings" will offer parallel workshops dedicated to new reseach results on energy-efficient and sustainable buildings. A novelty in 2019 is the "Industrial Energy Efficiency Conference" foccusing on innovation, markets and best practices for the industrial energy transition.

"Renewables second": The European Pellet Conference

Pellets are a clean, CO_2 neutral and convenient fuel with growing market shares worldwide. The **European Pellet Conference**, the largest annual pellet event in the world, delivers the latest news about markets, technologies and policies. Upper Austria is an ideal location for this conference: more than 25 % of all automatic biomass boilers sold in the EU are manufactured by Upper Austrian companies and pellet heating systems have become a standard solution in the region.

Welcoming the next generation

Achieving the global clean energy transition needs young and innovative thinkers! Since 2012, the WSED offer Young Energy Researchers an opportunity to present their work and achievements to an international audience. In the context of a call for papers, young researchers from all over the world submit their work in the fields of biomass and energy efficiency. In 2018, nearly 100 proposals were received from 46 countries. The conference's two most outstanding contributions are honoured with the **Best Young Energy Researcher Awards** (Biomass and Energy Efficiency), a highlight of the **Young Energy Researchers Conference**.

Full package deal – a leading tradeshow

The **Energiesparmesse**, a leading tradeshow on energy efficiency and renewable energy, takes place in parallel to the WSED. With nearly 100,000 visitors and 1,600 exhibitors each year, it presents product innovation in energy efficiency and renewables in buildings.

Upper Austria – a leading European region in the clean energy transition

The World Sustainable Energy Days are organised by the OÖ Energiesparverband, the energy agency of Upper Austria. Upper Austria, one of Austria's 9 regions, is well on its way in the clean energy transition: 76 % of the electricity, 60 % of all space heating and 32 % of the primary energy come from renewa-

bles. Through significant increases in energy efficiency and renewable energy, greenhouse gas emissions from buildings have been reduced by 43 % in 10 years.

Upper Austria has established itself internationally as a pioneer region for the development and uptake of innovative energy technologies. The OÖ Energiesparverband drives the energy transition in Upper Austria. Among others, it manages a network of 140 energy technology companies with a total of 7000 employees (www.ctc-energy.at).

Mark your calendar for 27 February – 1 March 2019 and come join REHVA and the worldwide energy efficiency community in Wels/Austria at the World Sustainable Energy Days! ■

World Sustainable Energy Days 2019

LAND OBERÖSTERREICH

OÖENERGIESPARVERBAND

Registration and further information: www.wsed.at

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Eurovent certification guarantees that the product has been submitted for an independent check and has been honestly and correctly graded.

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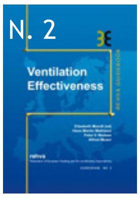
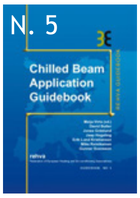
REHVA GUIDEBOOKS

written by teams of European experts



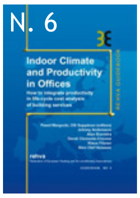
Ventilation Effectiveness

Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher costs and energy consumption associated with increasing the ventilation rates. This Guidebook provides easy-to-understand descriptions of the indices used to measure the performance of a ventilation system and which indices to use in different cases.



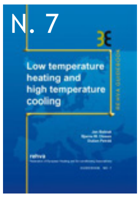
Chilled Beam Application Guidebook

Chilled beam systems are primarily used for cooling and ventilation in spaces, which appreciate good indoor environmental quality and individual space control. Active chilled beams are connected to the ventilation ductwork, high temperature cold water, and when desired, low temperature hot water system. Primary air supply induces room air to be recirculated through the heat exchanger of the chilled beam. In order to cool or heat the room either cold or warm water is cycled through the heat exchanger.



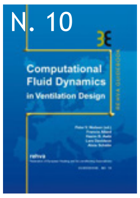
Indoor Climate and Productivity in Offices

This Guidebook shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available. The quantitative relationships presented in this Guidebook can be used to calculate the costs and benefits of running and operating the building.



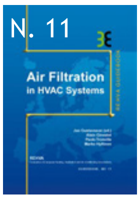
Low temperature heating and high temperature cooling

This Guidebook describes the systems that use water as heat-carrier and when the heat exchange within the conditioned space is more than 50% radiant. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in all types of buildings and work with heat carriers at low temperatures for heating and relatively high temperature for cooling.



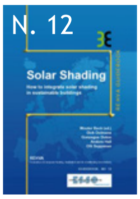
Computational Fluid Dynamics in Ventilation Design

CFD-calculations have been rapidly developed to a powerful tool for the analysis of air pollution distribution in various spaces. However, the user of CFD-calculation should be aware of the basic principles of calculations and specifically the boundary conditions. Computational Fluid Dynamics (CFD) – in Ventilation Design models is written by a working group of highly qualified international experts representing research, consulting and design.



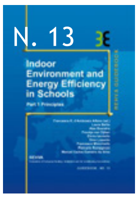
Air Filtration in HVAC systems

Air filtration Guidebook will help the designer and user to understand the background and criteria for air filtration, how to select air filters and avoid problems associated with hygienic and other conditions at operation of air filters. The selection of air filters is based on external conditions such as levels of existing pollutants, indoor air quality and energy efficiency requirements.



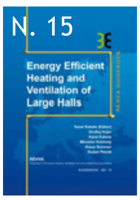
Solar Shading

Solar Shading Guidebook gives a solid background on the physics of solar radiation and its behaviour in window with solar shading systems. Major focus of the Guidebook is on the effect of solar shading in the use of energy for cooling, heating and lighting. The book gives also practical guidance for selection, installation and operation of solar shading as well as future trends in integration of HVAC-systems with solar control.



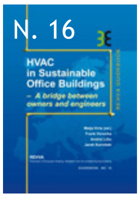
Indoor Environment and Energy Efficiency in Schools

School buildings represent a significant part of the building stock and also a noteworthy part of the total energy use. Indoor and Energy Efficiency in Schools Guidebook describes the optimal design and operation of schools with respect to low energy cost and performance of the students. It focuses particularly on energy efficient systems for a healthy indoor environment.



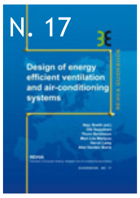
Energy Efficient Heating and Ventilation of Large Halls

This Guidebook is focused on modern methods for design, control and operation of energy efficient heating systems in large spaces and industrial halls. The book deals with thermal comfort, light and dark gas radiant heaters, panel radiant heating, floor heating and industrial air heating systems. Various heating systems are illustrated with case studies. Design principles, methods and modelling tools are presented for various systems.



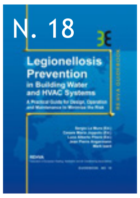
HVAC in Sustainable Office Buildings

This Guidebook talks about the interaction of sustainability and heating, ventilation and air-conditioning. HVAC technologies used in sustainable buildings are described. This book also provides a list of questions to be asked in various phrases of building's life time. Different case studies of sustainable office buildings are presented.



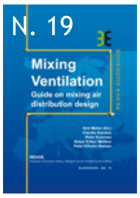
Design of energy efficient ventilation and air-conditioning systems

This Guidebook covers numerous system components of ventilation and air-conditioning systems and shows how they can be improved by applying the latest technology products. Special attention is paid to details, which are often overlooked in the daily design practice, resulting in poor performance of high quality products once they are installed in the building system.



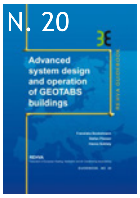
Legionellosis Prevention in Building Water and HVAC Systems

This Guidebook is a practical guide for design, operation and maintenance to minimize the risk of legionella in building water and HVAC systems. It is divided into several themes such as: Air conditioning of the air (by water-humidification), Production of hot water for washing (fundamentally but not only hot water for washing) and Evaporative cooling tower.



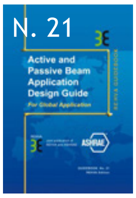
Mixing Ventilation

In this Guidebook most of the known and used in practice methods for achieving mixing air distribution are discussed. Mixing ventilation has been applied to many different spaces providing fresh air and thermal comfort to the occupants. Today, a design engineer can choose from large selection of air diffusers and exhaust openings.



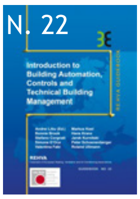
Advanced system design and operation of GEOTABS buildings

This guidebook provides comprehensive information on GEOTABS systems. It is intended to support building owners, architects and engineers in an early design stage showing how GEOTABS can be integrated into their building concepts. It also gives many helpful advices from experienced engineers that have designed, built and run GEOTABS systems.



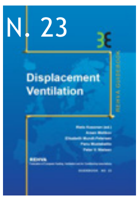
Active and Passive Beam Application Design Guide

This Guidebook is the result of collaboration by worldwide experts. It provides energy-efficient methods of cooling, heating, and ventilating indoor areas, especially spaces that require individual zone control and where internal moisture loads are moderate. This publication provides up-to-date tools and advice for designing, commissioning, and operating chilled-beam systems to achieve a determined indoor climate and includes examples of active and passive beam calculations and selections.



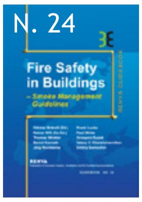
Introduction to Building Automation, Controls and Technical Building Management

This Guidebook provides an overview on the different aspects of building automation, controls and technical building management and steer the direction to further in depth information on specific issues, thus increasing the readers' awareness and knowledge on this essential piece of the construction sector puzzle. It focuses on collecting and complementing existing resources on this topic in the attempt of offering a one-stop guide.



Displacement Ventilation

The aim of this Guidebook is to give the state-of-the art knowledge of the displacement ventilation technology, and to simplify and improve the practical design procedure. The Guidebook discusses methods of total volume ventilation by mixing ventilation and displacement ventilation and it gives insight of the performance of the displacement ventilation. It also shows practical case studies in some typical applications and the latest research findings to create good local micro-climatic conditions.



Fire safety in buildings. Somke Management Guidelines

This guidebook describes the different principles of smoke prevention and their practical implementation by way of natural and mechanical smoke extraction systems, smoke control by pressurization systems and appropriate partition measures.

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