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Cover photo: Messeturm from street level [Wikimedia Commons]. The MesseTurm (English: Trade Fair Tower) is a 63-storey, 257 m (843 ft)[5] skyscraper in Frankfurt, Germany.

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The implementation of the new EPB-standards EU-wide will boost product innovation and create new market opportunities for our HVAC industry

JAAP HOGELING
Editor-in-Chief

The EPB standards will be published for Final Vote by November 2016. The next step is implementation of these EPB standards. EU broad implementation is an urgent matter! The increasing urgency for measures to achieve the COP21 targets activates the different stakeholders: the local and national authorities, the energy providers/producers and those responsible for new and to renovate buildings and building systems. Actions to meet the CO_2 emission reduction (COP21 target) and fossil fuel import reduction (additional EU target). Apart from the regulating authorities two main actors can be considered:

- the building and building services industry responsible for reducing the energy use;
- the energy providers/producers working on the decarbonisation of the energy grids.

These two groups are supplementary but also two sides of the balancing scale. CO_2 emission reduction and the dependence on imported fossil fuels are the main drivers for our European energy policy. When energy providers/producers will be successful to realise a high level of decarbonisation of the grid and at the same time reducing the imported amount of fossil fuels the urgency for the building industry may become less? This may help our industry, as this may lead to higher energy prices which will ease the cost-effectiveness of energy saving measures in the build environment. But this may also reduce our market opportunities. If the electricity grid becomes more sustainable which means that the non-renewable Primary Energy Factor and the CO2 emission factor will decrease (see table B16 in EN ISO/52000-1). This results automatically in a better Energy Performance (where the energy use is expressed in kWh/m².y based on the non-renewable energy fraction producing CO2 emissions) for buildings without improving their thermal properties or system efficiency. This means there will be less incentive to reduce the energy use. This may slow down the innovation and weaken the positioning of the EU producers on the global market. Product innovation and more efficient HVAC systems are a key issue to reduce the energy use in buildings. Innovation will only happen if applying new (very often already existing) technologies are cost-effective, easy and without barriers due to typical national assumptions. Using the harmonised procedures of EPB system standards will contribute substantially. Therefor it is most urgent that all stakeholders support the use of the new set of EPB standards throughout Europe in a harmonised way. All stakeholders: industry, consultants, installers and contractors should support the use of the EPB-standards and use their influence to convince their regulators to include this in their national building regulation. When the EPB standards are published next year it is up to us, the building and building system industry and professionals, to support the implementation EU wide. REHVA could be of help in supporting their members who play in most EU countries a key role in the communication with industry, regulators and educators. Currently initiatives are being elaborated out to establish an EPB-standards implementation network (EPB Center) to support the dissemination actions needed EU-wide and on national level. ■

EPBD: the "software proof" check of the CEN / ISO standards
– from the methodology to practial tools




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Keywords: EU Energy Performance Buildings Directive; CEN ISO EPB Standards; Software

Abstract

The European Commission gave a mandate to CEN (mandate 480) to develop a standardized methodology to calculate the energy performance of buildings (EPB) as required by the Recast-EPBD [1]. Around 50 CEN / ISO standards were developed.

To check the consistency of the whole methodology it was decided to develop a test software. For a few well- chosen standards, software modules have been developed and integrated in a test software tool (the tool and the source code can be downloaded at: http://dimn-cstb.fr/centool/default.html).

A standard representation was developed to visualize and check the calculation sequences between the different modules defined in the standardized methodology. The sequences are represented by SYSML diagrams and a short description per service following the overall sequence numbering. The operating condition inputs and outputs needed for each module to communicate with other modules have been checked and resumed in tables.

The developed test software, based on the methodology described in the set of CEN / ISO standards, shows that the standards could be linked together in a useable software and that the overall methodology is coherent. The help of the standard writers was useful and needed to clarify some "grey zones". These additional information is described in the software tool report [1]. The test software is delivered with a complex multizoning and multigenerator example test case using an hourly calculation interval.

1 EPBD: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings. Recast-EPBD: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings; (recast).

To parameter the example in the test software detailed information on the building components are needed. Many of these concern the properties of construction elements, which is the basic information that any EPB calculation method requires. As it was not the task of the test software to develop user-friendly interfaces, the usability of the methodology must be increased to be able to apply the EPBD methodology in practice. User friendly interfaces and links to product data bases are needed. Several examples already show how the dozens of data needed to describe for example a heat pump can be reduced to one mouse click.

To bring the standards to application, the urgent task is now to move from the methodology to commercial software tools. It is proposed to develop a software kernel, as it was done in the United States and in France for the national calculation tools. Commercial software companies could use this kernel as a basis to develop a complete commercial software tool with user friendly interfaces. This software kernel could also be used to certify commercial software tools.

Introduction

The European Commission gave a mandate to CEN (mandate 480) to develop a standardized methodology to calculate the energy performance of buildings (EPB) required by the Recast-EPBD.

The EPB calculation methodology has to take into account the characteristics of the building envelope (insulation, windows, etc.), the characteristics of the technical systems (heating, cooling, ventilation, domestic hot water, lighting), the building automation and control systems and the indoor air quality. The needed standards were developed or updated by different technical committees (CEN: TC 89, TC 156, TC169, TC 228, TC 247, ISO: TC 163, TC 205). Finally, around 50 standards were developed. This high number is necessary to be able to update the different standards individually.

The challenge was to coordinate the technical work of all these committees so that the different standards fit together in order to be able to calculate the EPB. A technical committee (TC 371) was created. TC 371 defined a modular structure (see **Figure 1**) and worked out an overarching standard (EN ISO 52000-1 see [2]) allowing to reference the whole methodology easily by one reference.

To check the different standards and the consistency of the whole methodology it was decided to develop a test software.

The control and consistency check was done in 2 steps:

1. each standard itself was checked by an Excel sheet (the Excel files are publicly accessible at web site*.

2. for a few well- chosen standards, software modules have been developed. To prove the usability of the modular structure (consistency of input, output data) of the overall methodology a test case was defined.

This second step is described hereafter.
In the standards, several calculation intervals and methods are described, for example:

- hourly, monthly or even yearly calculation intervals;
- the bin method.

For the consistency check only the hourly method was applied.

Content of the consistency check by the software tool

The developed tool is an Integrated Test Framework (ITF) that plays the role of the test software where the selected modules interact. It is as such complementary to the individual test required for each module (the earlier mentioned Excel sheets belonging to each EPB-calculation standard).

The software tool checked the following topics:
- Consistency of the calculation sequence and hierarchy of calculations;
- Availability of module inputs from the output of some other modules.

Documentation and check of the calculation sequence of the modules

The calculation of the energy performance of buildings using the CEN / ISO EPB standards is described in modules (see **Figure 1**). These modules will interact via the inputs and outputs. The output of one module is the input to another module (or modules). Therefore, the calculation needs to be performed in a specific order (calculation sequence) defined in the standards (overarching standard EN ISO 52000-1 and general standards of each service eg. EN 15316-1 see [3]).

* https://isolutions.iso.org/ecom/public/nen/Livelink/open/35102456)

Overarching			Building (as such)			Technical Building Systems		
	Descriptions	Standards		Descriptions	Standards		Descriptions	Heating
sub1	M1		sub1	M2		sub1		M3
1	General	(EN ISO 52000-1 CEN ISO/TR 52000-2	1	General	--	1	General	EN 15316-1
2	Common terms and definitions; symbols, units and subscripts	(EN ISO 52000-1 CEN ISO/TR 52000-2	2	Building Energy Needs	EN ISO 52016-1, EN ISO 52017-1 CEN ISO/TR 52016-2	2	Needs	
3	Applications	(EN ISO 52000-1 CEN ISO/TR 52000-2	3	(Free) Indoor Conditions without Systems	EN ISO 52016-1, EN ISO 52017-1 CEN ISO/TR 52016-2	3	Maximum Load and Power	EN 12831-1
4	Ways to Express Energy Performance	EN ISO 52003-1 EN ISO 52003-2	4	Ways to Express Energy Performance	EN ISO 52018-1 CEN ISO/TR 52018-2	4	Ways to Express Energy Performance	EN 15316-1
5	Building Functions and Building Boundaries	(EN ISO 52000-1 CEN ISO/TR 52000-2	5	Heat Transfer by Transmission	EN ISO 13789 EN ISO 13370 EN ISO 6946 EN ISO 10211 EN ISO 14683 CEN ISO/TR 52019-2 EN ISO 10077-1 EN ISO 10077-2 EN ISO 12631	5	Emission & control	EN 15316-2 EN 1500 CEN/TR15500 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5
6	Building Occupancy and Operating Conditions	EN 16798-1 CEN/TR 16798-2 (ISO 17777-1, ISO/TR 17777-2)	6	Heat Transfer by Infiltration and Ventilation	EN ISO 13789	6	Distribution & control	EN 15316-3 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5
7	Aggregation of Energy Services and Energy Carriers	(EN ISO 52000-1 CEN ISO/TR 52000-2	7	Internal Heat Gains	See M1-6	7	Storage & control	EN 15316-5 EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5
8	Building Zoning	(EN ISO 52000-1 CEN ISO/TR 52000-2	8	Solar Heat Gains	EN ISO 52022-3 EN ISO 52022-1 CEN ISO/TR 52022-2	8	Generation & control	EN 12098-1 CEN/TR 12098-1 EN 12098-3 CEN/TR 12098-3 EN 12098-5 CEN/TR 12098-5 EN 15316-4-1 EN 15316-4-2 EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-6 EN 15316-4-8
9	Calculated Energy Performance	(EN ISO 52000-1 CEN ISO/TR 52000-2	9	Building Dynamics (thermal mass)	EN ISO 13786	9	Load dispatching and operating conditions	
10	Measured Energy Performance	(EN ISO 52000-1 CEN ISO/TR 52000-2	10	Measured Energy Performance	- -	10	Measured Energy Performance	EN 15378-3
11	Inspection	- -	11	Inspection	(existing standards on IR inspection, airtightness, ...)	11	Inspection	EN 15378-1
12	Ways to Express Indoor Comfort	EN 16798-1 CEN/TR 16798-2 (ISO 17777-1, ISO/TR 17777-2)	12	--		12	BMS	
13	External Environment Conditions	EN ISO 52010-1 CEN ISO/TR 52010-2						
14	Economic Calculation	EN 15459-1						

Figure 1. EPB standards in the EPB modular structure (EN ISO 52000-1).

Cooling M4	Ventilation M5	Humidification M6	Dehumid-ification M7	Domestic hot water M8	Lighting M9	Building auto-mation & control M10	Electricity production M11
EN 16798-9 CEN/TR 16798-10	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 15316-1	EN 15193-1	EN 15232 CEN/TR 15232	
				EN 12831-3	prEN 15193-1		
EN 16798-11 CEN/TR 16798-12				EN 12831-3			
EN 16798-9 CEN/TR 16798-10	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 16798-3 (EN 13779 rev.) CEN/TR 16798-4	EN 15316-1	EN 15193-1 CEN/TR 15193-2	EN 15232 CEN/TR 15232	
EN 15316-2 EN 15500 CEN/TR 15500	EN 16798-7 CEN/TR 16798-8 EN 15500 CEN/TR 15500	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2			EN 15232 CEN/TR 15232	
EN 15316-3	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2			EN 15316-3		EN 15232 CEN/TR 15232	
EN 16798-15 CEN TR 16798-16				EN 15316-5 EN 15316-4-3		EN 15232 CEN/TR 15232	
EN 16798-13 CEN/TR 16798-14 EN 15316-4-2 EN 15316-4-5	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-2	EN 16798-5-1; EN 16798-5-2 CEN/TR 16798-6-1 CEN/TR 16798-6-22	EN 15316-4-1 EN 15316-4-2 EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-6		EN 15232 CEN/TR 15232	EN 15316-4-3 EN 15316-4-4 EN 15316-4-5 EN 15316-4-7
						EN 15232 CEN/TR 15232	
				EN 15378-3	EN 15193-1 CEN/TR 15193-2	EN 15232 CEN/TR 15232	
EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 16798-17 CEN/TR 16798-18	EN 15378-1	EN 15193-1 CEN/TR 15193-2	WI 00247092	
						WI00247093	

The following general order is determined in the EPB standards:

1. **Initialize EPB calculation** for a building (time independent values module M1-5 and M1-8)
2. Initialize/get current time interval (calculation intervals) values
   a. Occupancy depending values (M1-6)
   b. Climate data (including solar radiation calculation depending on building model (M1-13)
3. Calculate the current time interval (uses the indoor climate of the previous time interval)
   a. DHW
   I. Needs (M8-2)
   II. Distribution (M8-1C, M8-6, M8-9)
   III. DHW Storage (M8-7) and DHW instant production (M (8-8)
   b. Lighting
   I. Needs (M9-2)
   II. Emission (M9-5)
   III. Distribution (M9-6)
   IV. Generation (M9-8)
   c. Ventilation
   I. System flow needs => required flow (M5-5) and flow temperature (M5-6 and M5-8 or M5-5)
   II. System flow delivered => supplied flow and flow temperature (M5-6 and M5-8)
   III. All air flows delivered (vents, windows, leaks and system) (M5-5)
   IV. AHU needs (thermal) (M5-6, M5-8, M6-5, M6-8, M7-5 and M7-8)
   d. Thermal conditions
   I. Heating and cooling set point correction (M3-5 and M4-5)
   II. Thermal needs (M2-2)
   e. Heating (+ DHW for generation part)
   I. Emission (M3-5)
   II. Distribution (M3-1C, M3-6, M3-9)
   III. Storage (M3-7 / M8-7) and Generation (M3-8 / M8-8)
   f. Cooling
   I. Emission (M4-5)
   II. Distribution (M4-6)
   III. Storage (M4-7)
   IV. Generation (M4-8)
   g. (Optionally repeated if required energy is not supplied) Thermal internal conditions (M2-2)
   h. Energy performance values (Mx-4 and Mx-10)
4. **Aggregate outputs** (consumed energy) of services (M1-7)
   Calculate the energy performance of **the whole year** (M1-9)

Each service (e.g. heating, cooling) consists of multiple modules exchanging data and which are called in a specific sequence. The software team developed a standard representation to visualize and check the calculation sequences between the different modules defined in the standardized methodology. The sequences are represented by SYSML diagrams and a short description per service following the overall sequence numbering is provided. Hereafter the example of the detailed call sequence for the software implementation of the DHW sequence is presented (**Figure 2**).

Documentation and check of the input/output interface for software implementation

Based on the module implementation in the ITF and following the calculation sequences, the operating condition inputs and outputs needed for each module to communicate with others modules, have been checked and resumed in tables.

A colour code was set up to indicate the correspondence between the parameters and names in the software and to highlight the missing parameters in the draft standards (see **Table 1**).

Hereafter the example of Module M3-5: Space Heating Emission systems & Control (EN 15316-2) is provided (see **Table 2 and 3**)

The software tool team was able to develop the test software based on the methodology described in the set of CEN / ISO standards. This shows that the standards and the overall methodology are coherent.

Of course there is still some fine tuning needed and the help of the standard writers was useful and necessary. This is not surprising taking into account the parallel development of such a huge number of standards in such a short time. Even in calculation software running now since years' inconsistencies are still identified.

Some of the needed corrections could be changed in the final drafts of the standards, but it was not possible to do it in all cases because some additional discussion would have been needed (for example where which parameter should be calculated, how to take into account Building Automation and Control). Among the main problems faced for example in TC228 standards was also the difficulty to deal with a monthly and an hourly method at the same time, in the same standard, without working out always two separate methods. For the set of EPBD standards the needed additional information to work out a software tool are described in the software tool report [1].

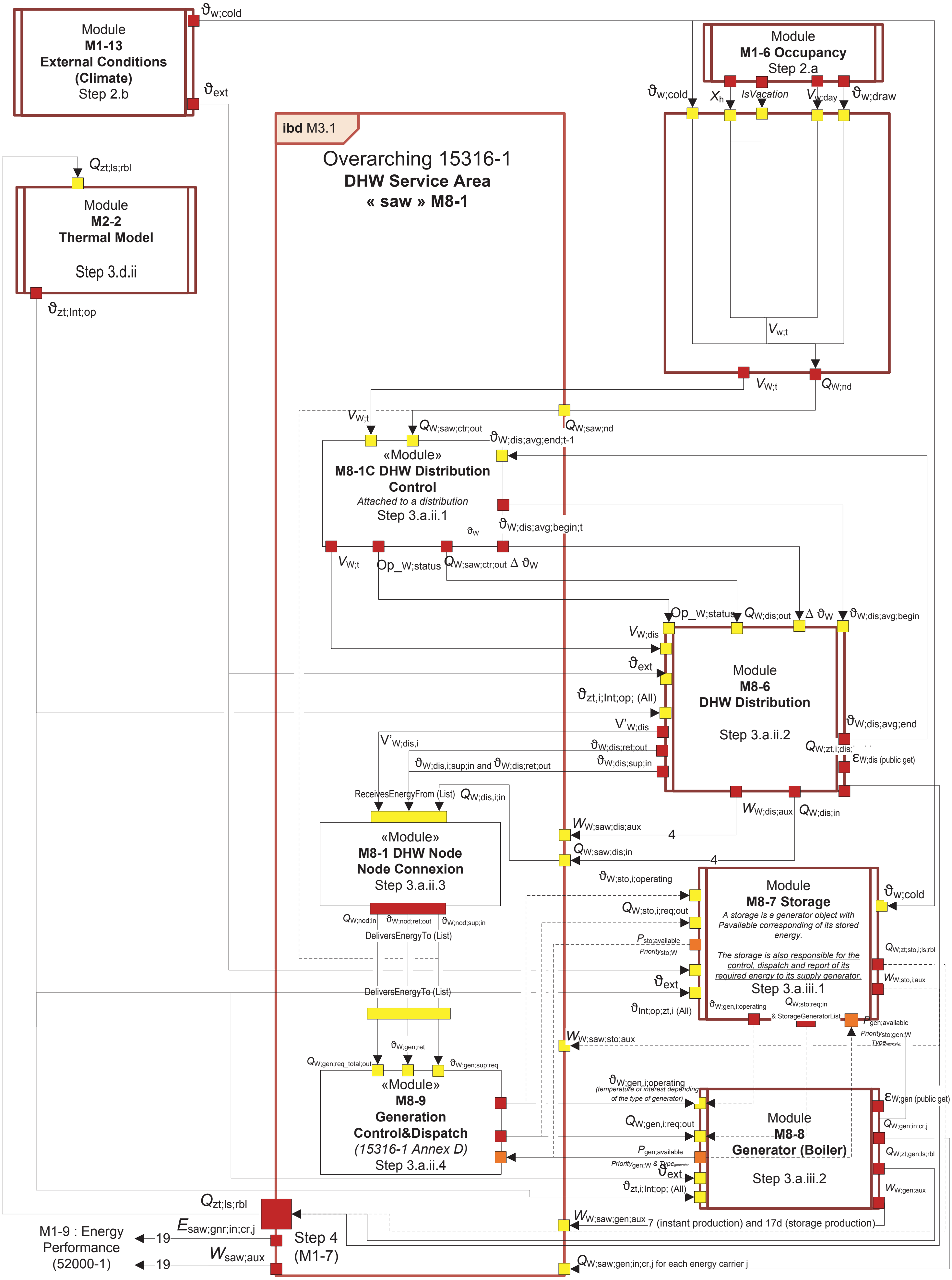

Figure 2. DHW calling sequence.

Table 1. Documentation of the input / output data per module.

Description	Symbol	Unit
Energy needs for DHW service area at current time step	$Q_{W;nd}$	kWh
Heating emission input in heating service area sah	$Q_{H;sah;em;in}$	kWh
Heating authorization for the current time step	IsHeating	Bool
Total recoverable heating distribution system losses of the heating service area sah (for information)	$Q_{H;sah;dis;ls;rbl}$	*kWh*

← **Existing in the current EPB standard**

← **Existing in the current EPB standard but with a different symbol naming.**

← **Absent in the current EPB standard or present in equations but forget in the input/output table**

← No need to be put at this level except for information

Table 2. M3-5 Space Heating Emission and Control Inputs (Operating Conditions).

Description	Symbol in code	Unit	Comments	Symbol in the standard	Origin module
Heating Setpoint temperature in space s	$\theta_{H;s;set}$	°C	From Step 2.a	*Not present but use similarly to $\vartheta_{int,ini}$ equations*	**M1-6**
Heating authorization for the current time step in space s	IsHeating,sp	Bool	From Step 2.a		**M1-6**
Required thermal energy output of the heating emission system in space s	$Q_{H;s;em;req;out}$	kWh	Set at Step 3.e.i.1	$Q_{em;out}$	**M3-1**
Internal operative temperature of the space	$\theta_{s;Int;op}$	°C	Calculate at Step 3.g.(t-1)	$\theta_{int,ini}$	**M2-2**
External temperature	θ_{ext}	°C	Set at Step 2.b	θ_{e}	M1-13

Table 3. M3-5 Space Heating Emission and Control Outputs.

Description	Symbol in code	Unit	Comments	Symbol in the standard	Requested by module (receiver)
Corrected heating Setpoint temperature in space s	$\theta_{H;s;set;corr}$	°C	Step 3.d.i	"$\theta_{H;s;set} + \Delta\theta_{int;inc}$" (variation only and not corrected setpoint)	**M2-2**
Heating energy emission input in space s	$Q_{H;s;em;in}$	kWh	Step 3.e.i.2		**M3-1/M3-1C**
Recoverable heating emission system losses in space s	$Q_{H;s;em;ls;rbl}$	kWh	Step 3.e.i.2	"$Q_{em,ls}$" (total losses and not recoverable)	**M3-1**
Auxiliary energy of the heating emission system in space s	$W_{H;s;em;aux}$	kWh	Step 3.e.i.2	$W_{em,ls,aux}$	**M3-1**
Expenditure factor for the heating emission at current time step in space s	$\varepsilon_{H;s;em}$	-	Step 3.e.i.2	"$\varepsilon_{em;ls;an}$" (annual and not hourly)	**NONE** – For information (public get only)
Heating authorization for the current time step in space s	IsHeating,s	Bool	Step 3.e.i.2		**M3-1/M3-1C**
Nominal power of emitters	$P_{nom;em}$	kW	*Not a calculate data but need to be "public get" for other module*		***M3-1B***
Priority of the emitters	*Priority*	Int	*Not a calculate data but need to be "public get" for other module*		***M3-1B***

Validation example test case

To prove the usability of the modular structure, the software tool is delivered with an example test case (project.xml). The software team used the TC 89 team's test case example for the building energy needs as described in EN ISO/TR 52016-2 (single family house) and added the different service systems (heating, DHW, etc). The sizing of these systems is not perfect as it was done only approximately and this is reflected in the results. The precise value of each output is not so important as the example test case was used in prior to validate the correct implementation of modules and the overarching sequence in the software tool.

The example test case was transformed to a multi-zone example in order to test the most complex case. The building is on two levels; each level corresponds to a thermal zone (multi-zone case). The service areas are crossing both thermal zones.

The case represents a stand-alone house with a total of 176 m² net heated areas and 483 m³ net volumes. The house is assumed to be located in the centre of France (Allier – 03).

The house is occupied by 4 working people (outside of the house during the day and on holidays all August), consuming each 40 litres of DHW per day, distributed equally through the house (for internal gains calculation in both zones).

The heating is active only between the beginning of October and the end of April. Outside this period, the pump and circulation for heating are "Off". Inside this period, even without any needs, the pump and the heating loop circulation are "On", consume energy and have losses. Each level is equipped with water based heat emitters of 7000 W total capacity and electrical back-up emitters with 2000 W total capacity (multi- emitter case).

The DHW and heating needs are provided by the same two service condensing boiler (with "after 1994" EN15316-4-1 default parameters) with 28 kW capacity and located in level 1 (Thermal Zone 1) of the house.

Parameter of the example test case

The detailed XML description of this test case example is described in the software final report [1]. An extract is provided in **Table 4**.

Table 4. Example Test Case XML (extract).

```
<?xml version="1.0" encoding="utf-8"?>
<Project xmlns:xsi="http://www.
w3.org/2001/XMLSchema-instance"
xmlns:xsd="http://www.w3.org/2001/
XMLSchema">
 <Index>1</Index>
 <Name>Project1</Name>
 <Description>Desc</Description>
  <Buildings>
   <Building>
    <Index>1</Index>
    <Name>Building 1</Name>
    <Description>Desc</Description>
etc.
```

Results of the example test case

The software tool summarizes the results of the example test case (see **Table 5**) with the connected modules, except for ventilation for which a simplified model has been used.

More detailed outputs can also be provided.

Table 5. Resume of outputs (example).

		NEEDS			TOTAL DELIVERED ENERGY (emission, distribution, auxiliaries, generation losses)			TOTAL PRIMARY ENERGY (emission, distribution, auxiliaries, generation losses)		
	Area (m²)	Heating Needs	Cooling Needs	DHW Needs	Heating	Cooling	DHW	Heating	Cooling	DHW
building1 (kWh/m²)	176.8	23.74	0.00	9.76	37.59	0.00	23.50	48.47	0.00	25.90
Thermal zone1 (kWh/m²)	91.8	26.76	0.00							
Thermal zone2 (kWh/m²)	85	20.48	0.00							
SAH1 (kWh/m²)	176.8	23.74			37.59			48.47		
SAW1 (kWh/m²)	176.8			9.76			23.50			25.90

The time needed for the calculation, based on an hourly time interval depends on the system modules used, the amount of data to read and write. On a i7-4810MQ 2.8GHz processor it took approximately 1 minute to calculate a whole year including an additional initialization month. This is reached even without using multi-threading technology and any other optimization to speed the process.

The example test case confirmed that even for complex cases using an hourly calculation interval it is possible to develop and run a software based on the set of EPBD standards.

This type of tools is needed for example for the European Voluntary Certification Scheme for non- residential buildings and for high performing buildings as nearly-zero energy buildings.

The tool and the source code can be downloaded at http://dimn-cstb.fr/centool/default.html

Needed further developments - from the methodology to commercial software tools

The software team developed a test software with a few well-chosen modules to check if the standardized methodology of the EPBD standards is consistent and can be applied in a running software tool.

It is to be remembered that it was not the task of the software tool team to develop user friendly interfaces or a commercial software tool.

To parameter the example in the test software detailed information on the building components are needed. Many of these concern the properties of construction elements, which is the basic information that any EPB calculation method requires. As it was not the task of the test software to develop user-friendly interfaces, the usability of the methodology must be increased to be able to apply the EPBD methodology in practice. User friendly interfaces and links to product data bases are needed. Several examples already show how the dozens of data needed to describe for example a heat pump can be reduced to one mouse click.

There are several possibilities to develop such a software by the market. For example, the market could develop the complete software starting from the methodology, or the market could focus on the development of the user interfaces. For the American "Energy plus" software and the French RT2012 the State authorities financed the development of a kernel (focusing on the methodology) and provided it for free to the software developers to develop and commercialize a user-friendly commercial software. The French kernel was worked out by the people involved in the development of the methodology (the standard writers) with the assistance of software professionals. This solution is very efficient because there is no need that each software developer analyses the thousands of pages of the standards. This approach helps to assure that the kernel is completely in line with the methodology and vice versa and that the updating of the methodology and the kernel is coordinated.

This approach has also the big advantage to favour the dissemination of the method.

A software kernel is needed in any case as reference to set up the test procedure for the certification of the commercial software.

Resume

The software tool team confirmed that the tested EPBD modules are software proofed and consistence.

The urgent task is now to move from the methodology to commercial software tools to bring the standards to application.

It is proposed to develop a software kernel, as it was done in the United States and in France for the national calculation tools. Commercial software companies could use this kernel as a basis to develop a complete commercial software tool with user friendly interfaces. This kernel could also be used to certify the commercial software. ■

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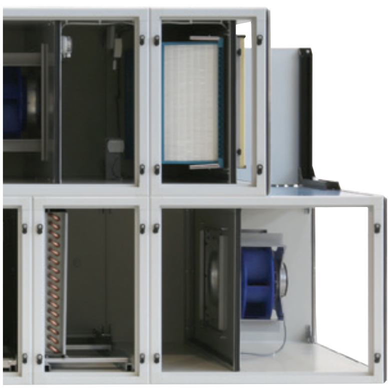
ADV Next Air

The air treatment evolution



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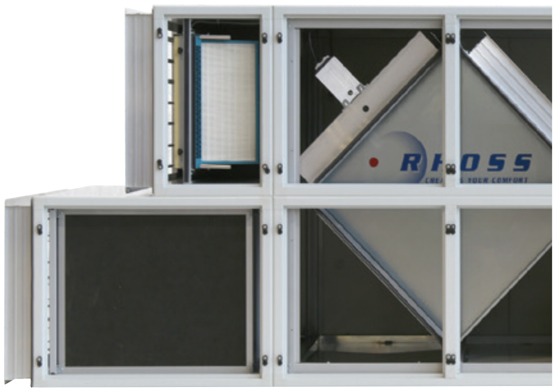

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Rapid, Transient, In-Situ Determination of Wall's Thermal Transmittance

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Large deviations observed between actual and theoretical gas consumption in dwellings cast a shadow of doubt on the accuracy of the Energy Labeling method. Generally, such problem can stem from two different aspects: the calculation system and the inputs being fed. As one of the most critical parameters, the thermal transmittance U-value has been investigated from both perspectives

Introduction

Buildings, accounting for nearly 40% of total energy consumption in Europe, play a key role in energy savings [1]. In the Netherlands, ISSO publication [2, 3, 4], as a part of EPBD (Energy Performance of Building Directive), prescribes calculation methods leading to an estimation of the gas and electricity consumption in buildings. However, the estimations have shown to be strongly deviating from the actual consumption [1,5].

The models applied to estimate the buildings' energy consumption (**Figure 1**) have shown to be very sensitive to some of the input parameters such as the wall's thermal transmittance U-value [6]. From the computational point of view, the problem seems to be the simplifications and the assumptions made whereas in the inspection viewpoint the main problem seems to be the lack of possibilities for quick and accurate on site measurement of the walls' conductive thermal resistance.

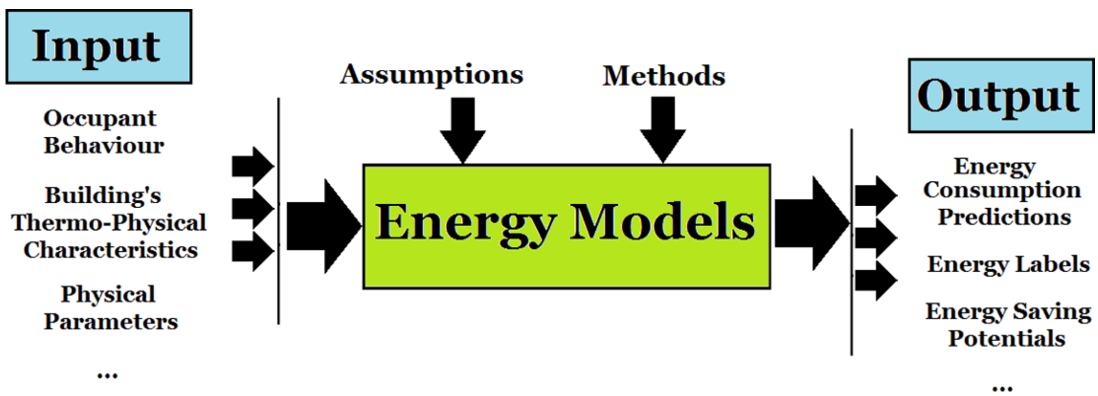

Figure 1. The general structure of a building's energy model, the inputs, the process, and the outputs.

In the Netherlands, in case of lack of information regarding this variable, which is mostly the case in older buildings, the U-value is not being measured, but suggested based on construction period [3], conveying a strong possibility of a very poor estimation taking place in such cases. A new method is proposed, applied, and validated experimentally on site for three case studies. Applying this method, it is possible to rapidly measure the Rc-value of an unknown construction on site.

Investigation of the sensitivity of building's energy consumption to the type of model used

In this part of the research, the dynamic effect of walls' heat storage due to the thermal mass is studied, applying dynamic simulations. Two dynamic methods (**Figure 2**), the Finite Difference and the Response Factor (RF) method [9] are used to simulate the effect of heat storage when aggregating from hourly calculations to monthly/yearly calculations.

Moreover, the energy labelling calculation method has been compared to a more complicated and detailed method using a thermal network. It has been shown why some simplifications made in the models based on energy labelling methods may be too radical. According to the simulations, the most obvious simplifications suspected to be playing a major role in overestimation of energy consumption include:

- Determination of heat transfer between adjacent rooms with identical air temperatures
- Definition of the combined radiative-convective heat transfer coefficients
- Different definitions of solar gains (by the surfaces or by the air)
- Including/excluding the solar gains by exterior surfaces such as roofs, etc.

It was concluded that the dynamic simulation of the walls does not change the results of energy demand prediction, as long as they are summed over a long period (e.g. weeks, months, seasons, year). However, for the hourly calculations, there is a clear discrepancy between the dynamic and static simulations, explaining a part of thermal comfort (e.g. wall's radiant temperature) and therefore occupant behavior. Moreover, certain simplifications within the energy labeling calculations are shown to be too radical and therefore responsible for a part of the overestimations. It is recommended to include more detailed modeling parameters using correction factors.

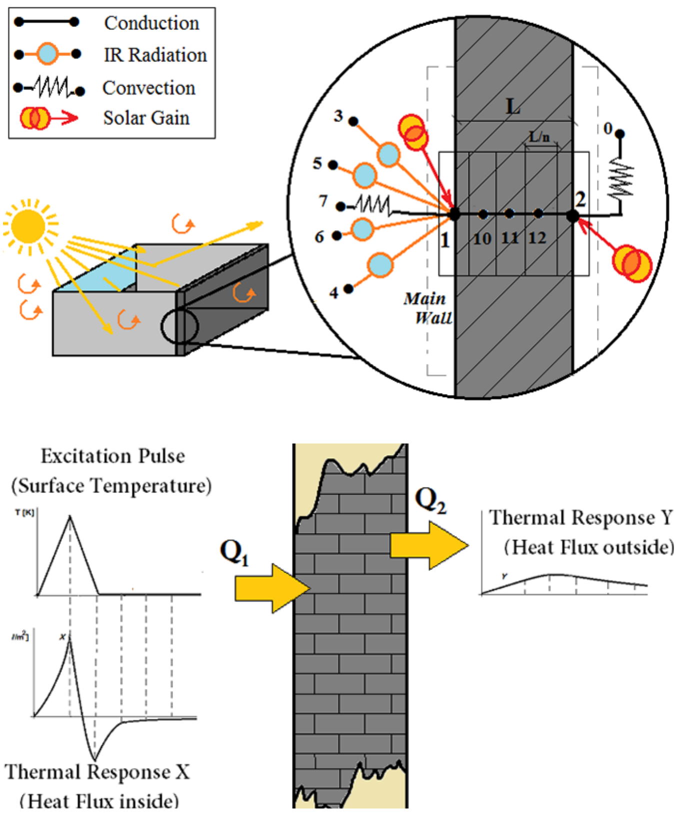

Figure 2. The Finite Difference method (top) and the Response Factors method (bottom).

A new method to measure wall's thermal transmittance in existing buildings

The primary method for in-situ measurement of the thermal resistance (Rc-value) is the heat flow meter method by the international standard ISO 9869 [10] and the American standard ASTM [11, 12], demanding a very long measurement period (up to more than 2 weeks). There is therefore a need for a new, quick, feasible, and cost-efficient method.

Excitation Pulse Method, EPM

A rapid in-situ measurement method was developed at Delft University of Technology and experimentally applied on three case studies. The fully transient method EPM, is based on the theory of RFs. The surface of the wall is exposed to a triangular temperature pulse. While the RFs are defined for a pulse with a magnitude of 1K, (see **Figure 1**), in EPM, the magnitude of the pulse is chosen as high as possible (up to 60°C). The RFs are then obtained using the heat flux, temperature, and the superposition principle (heat flux divided by the magnitude of the excitation pulse).

Once the RFs X and Y at both sides of the wall are obtained, the equivalent Rc-value is derived [7,8] as a function of X and Y through Eq. 1:

$$Rc = 2 \times \left(\sum_{i=0}^{n} (X_i + Y_i) \right)^{-1} \qquad (1)$$

Experimental Setup

An experimental setup was designed (**Figure 3**) to validate the proof of principle. A proper test area of the wall is allocated by IR thermography. Two thermocouples and two heat flux meters are mounted on two sides of the wall opposite to each other, covered by a layer of tape with the same color of the wall's surface. The linearity of the signal is controlled every 10 seconds. In order to damp the undesired temperature and heat flux fluctuations, an insulating box is mounted on the exterior surface of the wall.

Using an IR heater, a variable heat flow is exerted to the surface of the wall in such a way that a pre-defined triangular temperature profile is formed on the surface of the wall. The temperature is increased to reach its desired maximum (e.g. 80°C). After this point, the heat flow is decreased to cool down linearly to the zero level. A fan with variable power and distance is employed to remove the rest of the heat absorbed by the body of the wall. Finally, when the fan's highest speed is not enough, an ice bag is applied in combination with the fan to keep the surface temperature on a zero level. After a few time intervals, the test may stop.

The EPM is validated via comparison with the Average Method described in ISO9869 [10], in three different buildings (**Figure 4**). In the building from 1933, the

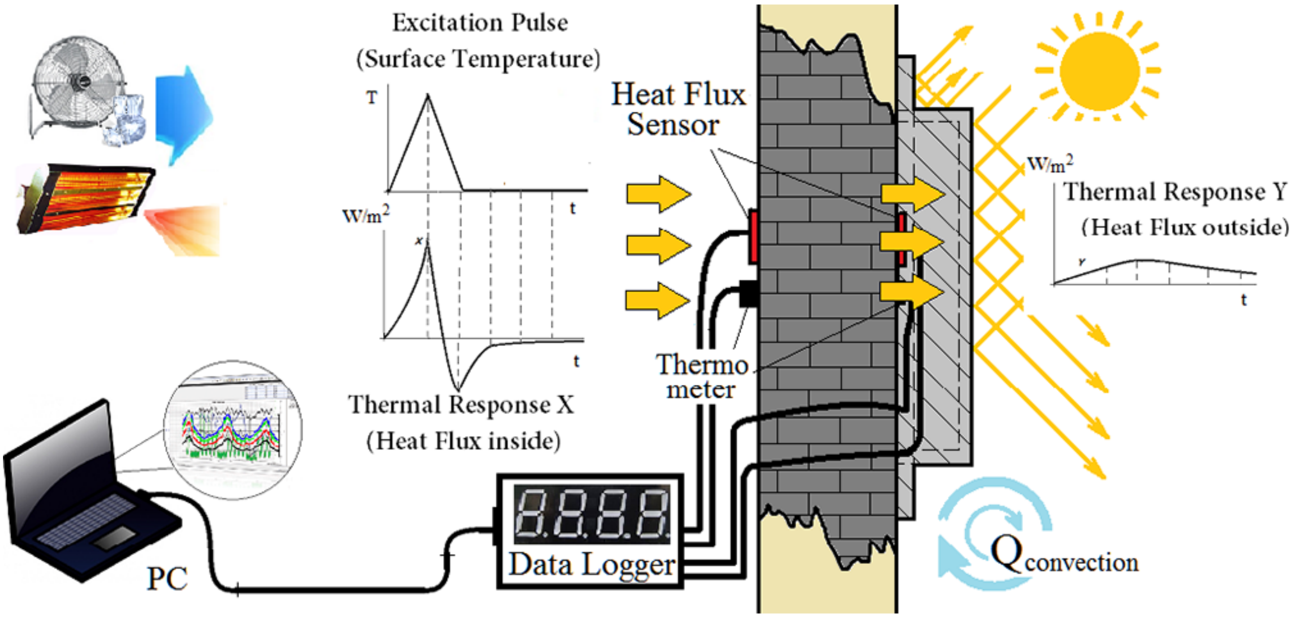

Figure 3. EPM experimental setup, linear heating followed by linear cooling, and measuring the RFs.

Figure 4. The three case studies studied by EPM and validated by ISO 9869 standard method.

type of construction (Dutch brick) was easy to determine and the Rc-value was calculated using brick's properties. EPM shows an agreement with this calculation.

Results of the Experiments

The results of the validation (**Table 1**) show that the Rc-values measured by the EPM are in a good agreement (less than 2% error) with the ones obtained applying ISO9869, implying that EPM is reliable.

Once validated, EPM has been applied to investigate the benefit of performing measurements rather than referring to the construction period as assumed in the Dutch labeling method (**Table 2**). It has been shown that such Rc-value default assumption can result in 88% underestimation, resulting in an overestimation of up to nearly 400% in thermal transmittance U-value, explaining a part of total energy consumption overestimation in older buildings.

Conclusion

From the experiments, it is concluded that EPM is quick, cost-efficient, and reliable. It helps measurement of the Rc-value of a wall within a couple of hours (in contrast with the current ISO standard requiring weeks of monitoring). EPM has an accuracy comparable to the existing standard and therefore, has the potential to be further developed and applied to energy labeling inspections. In case of unknown constructions, it is highly recommended to use EPM as an alternative to Rc-value suggestions based on construction periods. ■

Table 1. Results of the validation of EPM (1.5 hour measurement) and by ISO 9869 (14 days measurement).

Case Study	Rc-Value (ISO 9869)	Rc-Value (EPM)	Rc-Value (Calculated)	Departure
1	0.17 m^2KW^{-1}	0.17 m^2KW^{-1}	0.17 m^2KW^{-1}	−0.58%
2	0.77 m^2KW^{-1}	0.78 m^2KW^{-1}	–	+1.2%
3	1.57 m^2KW^{-1}	1.60 m^2KW^{-1}	–	+2.0%

Table 2. Comparison of values obtained by EPM and Dutch energy labeling default values based on construction year periods.

Parameter	Determination	Case Study 1	Case Study 1	Case Study 1
General Info	Construction Year	1933	1964	1680
	Energy Label	F	E	F
Rc-Value	Measured: EPM	0.172 m^2KW^{-1}	0.78 m^2KW^{-1}	1.6 m^2KW^{-1}
	Default value	0.19 m^2KW^{-1}	0.19 m^2KW^{-1}	0.19 m^2KW^{-1}
	Difference *	+5.6%	−76%	−88%
U-Value	Measured: EPM	2.92 $Wm^{-2}K^{-1}$	1.05 $Wm^{-2}K^{-1}$	0.56 $Wm^{-2}K^{-1}$
	Default value	2.76 $Wm^{-2}K^{-1}$	2.76 $Wm^{-2}K^{-1}$	2.76 $Wm^{-2}K^{-1}$
	Difference	−10%	+163%	+393%

* The differences are mainly caused by the fact that the default values are, irrespective of the real construction, based on the construction year where no insulation or cavity wall is assumed, these default are used for buildings build before 1965. A calculation based on the real construction properties, which cannot be obtained without destructive survey is expected to show smaller differences.

About the Article "Rapid, Transient, In-Situ Determination of Wall's Thermal Transmittance"

The article is based on a research entitled "Computational and Experimental Investigation of Wall's Thermal Transmittance in Existing Buildings", done in the Netherlands at Delft University of Technology. During REHVA 12th world congress, CLIMA 2016, Aalborg, Denmark, two student competitions took place: On May 23rd 2016, REHVA International Student Competition and on May 24th, REHVA World Student Competition. Arash Rasooli, who had done this research for his M.Sc. thesis in Mechanical Engineering, at Delft University of Technology, won the 1st place in both competitions.

REHVA International Student Competition 2016

Under the leadership of Manuel Gameiro da Silva, REHVA Vice-President from Portugal, fifteen candidates representing twelve European countries were in competition. After the deliberation, the jury declared winner Arash Rasooli for his work on "Computational and Experimental Investigation of Wall's Thermal Transmittance in Existing Buildings".

REHVA World Student Competition 2016

Under the leadership of past President Karel Kabele, seven candidates out of five countries amongst REHVA's international partners (ASHRAE, CCHVAC, ISHRAE, SHASE and SAREK) were in competition. The winner of the REHVA International Student Competition, Arash Rasooli, took also part in this competition, representing Europe. After the deliberation, the jury declared winner Arash Rasooli for his work on "Computational and Experimental Investigation of Wall's Thermal Transmittance in Existing Buildings".

Two trophies, two financial prizes, and four certificates were offered to the winner. The following article summarizes the winning research.

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Renewable energy technology feasibility study for a new hotel building in Amsterdam




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This article discusses the economic and environmental feasibility of applying renewable energy technology (RET) to a new hotel building in Amsterdam using the simulation software HOMER. The study shows that applying PV including a surface up to 750m² can be both economical and environmentally feasible and that achieving a Renewable Fraction (RF) of above 75% at the hotel building in Amsterdam goes along with an increasing life cycle cost (LCC). Besides PV, other renewable energy technologies as micro wind-turbine and CHP are investigated.

Keywords: hotel; renewable energy technology; wind; photo voltaic; biomass; life cycle cost; renewable fraction; optimization software, HOMER, combined heat and power.

Background

The energy consumed by hotel buildings is relatively large compared to the consumption of other commercial buildings. A typical hotel's (<100 beds) annual energy use ranges from 250 to 350 kWh/m² and for large hotels (>100 beds) it ranges from 450 to 700 kWh/m², versus a typical commercial building's energy use between 30 and 152 kWh/m² [1,2]. Another characteristic of hotel buildings is their unique energy profile. Specific characteristics of the hotel sector are 24-h operation, high degree of comfort provision, low tolerance for failure and the occurrence of two daily load peaks [3].

Generation of energy from renewable sources to cover a buildings energy demand contributes to the reduction of the environmental impact of buildings. There is a shortage of literature about hotel building case studies in Europe, while the specific hotel energy characteristics necessitate a separate assessment of RET viability studies in this sector.

Case study

The current study is a cooperation between the company Croonwolter&dros, specialist in building services, and the Technical University of Eindhoven. The design of the hotel building is awarded with a platinum LEED certificate, the highest possible award regarding sustainability. This certification is mainly merit to sustainable measures as a grey water system, green roof area, CHP running on BIO-oil and the usage of sustainable and local materials. The thermal energy demand is decreased by an adaptable façade which responds to the outdoor weather conditions by increasing the overall U-value and by the regulation of the sun admittance.

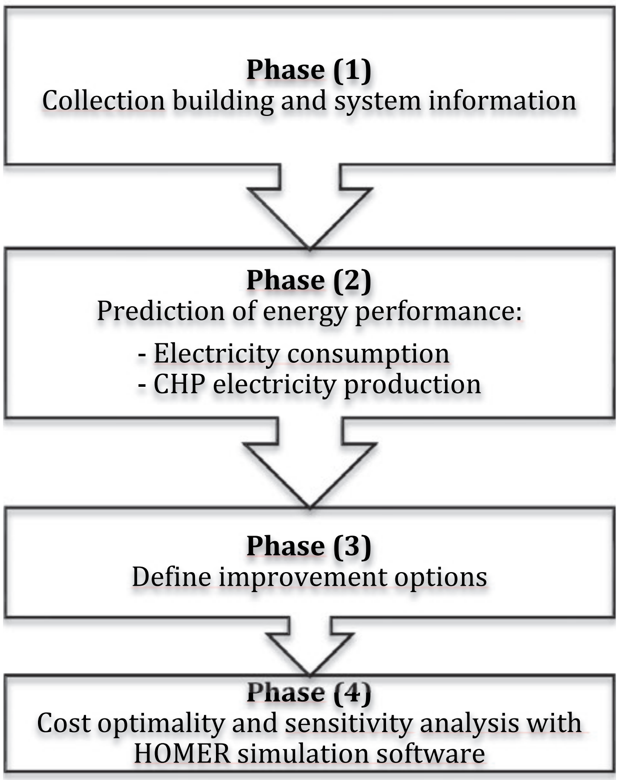

Figure 1. Applied methodology expressed in 4 research phases.

Renewable technology generation as PV and wind turbines is currently not included in the hotel's energy supply system.

The research aim is to investigate the economic and environmental feasibility of applying more renewable energy technology in the current design of the hotel.

Methodology

HOMER – Modeling software for energy supply systems was used to examine the research aims. HOMER, produced by the National Renewable Energy Laboratory, US [4] was chosen as the primary application for this study due to its extensive use in previous RET case studies [5,6] and RET validation tests [7,8]. HOMER is an optimization software package which simulates electrical energy supply system configurations, including energy from renewable sources, and scales them on the basis of LCC and technical feasibility. The proposed methodology in this research is shown in **Figure 1**, consisting of 4 research phases.

Energy system (Phase 1)

A simplified overview of the hotel's energy supply system is shown in **Figure 2**. The domestic hot water (DHW) demand is mainly supplied by a heating tracked combined heat and power (CHP) generator running on BIO-oil which makes it a renewable energy source. An electricity driven, ground source heat pump is the main source for space heating and cooling. The hotel is connected to the district heating to serve the DHW demand and space heating as a back-up for the CHP or heat pump. As a secondary output, the CHP produces electricity which directly serves the electricity demand of the hotel. The remaining electricity needed by the hotel, is in the current energy supply system provided

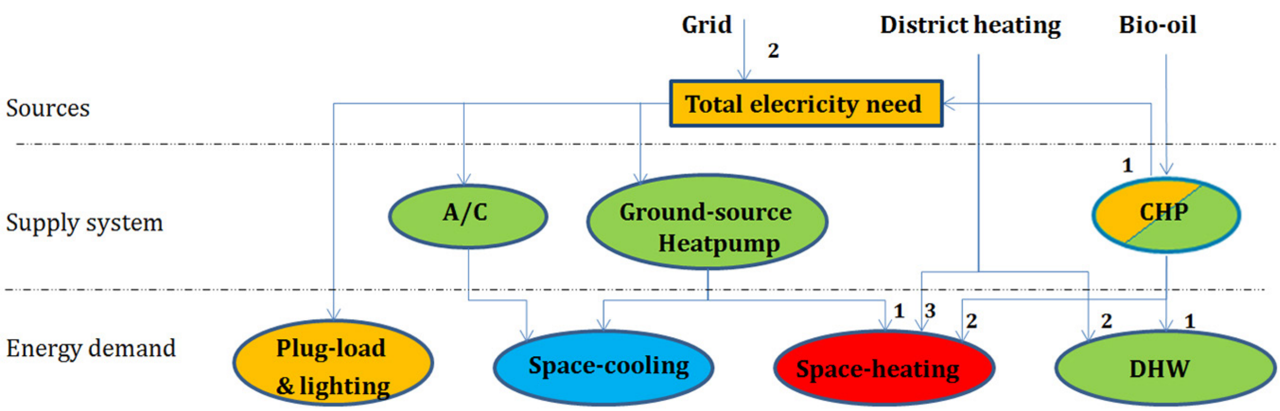

Figure 2. Simplified overview of hotel's energy supply system where the priority in consumption is addressed by numbers; the DHW demand is supplied by the CHP and is in case of excessive demand also supplied by district heating.

by the grid. In this research, a renewable solution for the resulting grid demand is investigated. Hence these main consumers, including the electricity production of the CHP; strongly influence the resulting electricity need of the grid, a prediction of all four energy demand sides of the hotel building had to be made.

Energy performance prediction (Phase 2)

A prediction of the space cooling and space heating is performed with the building performance simulation program IES VE, which produces the hourly heating and cooling demand over a year. The prediction of the plug load, lighting and the DHW demand is based on statistics of reference hotel buildings [9], taking into account the expected occupancy of hotels in Amsterdam [10]. An overview of the expected occupancy profile is shown in **Table 1**.

The hourly electricity production in a heating tracked CHP depends on the hourly demand for DHW. The ratio electricity production-heat production (r) is used to calculated the hourly electricity production of the CHP. (r) is determined as shown in equation 1:

$$r = \frac{\eta_h}{\eta_e} \qquad \text{(eq. 1)}$$

Where:
r = heating to power ratio (0.65);
η_e = annual electrical efficiency CHP;
η_h = annual heat efficiency CHP.

The impact of part load on the CHP and ground source heat pump is not taken into account. The heat pump and CHP efficiencies therefore are overestimated, leading to a decreased resulting electricity need from the grid. The results of the RET feasibility study could in reality be more optimistic, as a larger percentage of renewable electricity produced on own site could be used for own consumption, rather than be sold back to the grid or stored in batteries.

Table 1. Expected occupancy profile used for the energy performance prediction [10].

Timeframe	Occupancy
January-April	60%
May-August	100%
September-December	80%

Results energy performance prediction

The results of the annual expected electricity flows in the hotel are shown in **Table 2**. **Figure 3** shows a typical daily pattern of the electricity flows in the hotel, where the typical characteristics as 24h operation and two daily peaks in the morning and evening [3] are visible. More detailed information about the prediction and the results can be derived from the full version of the master-thesis [11].

Table 2. Predicted annual electricity flows in the hotel.

Timeframe	Occupancy
Total electricity consumption	930 [MWh/yr]
CHP electricity production	538 [MWh/yr]
Grid electricity consumption	392 [MWh/yr]

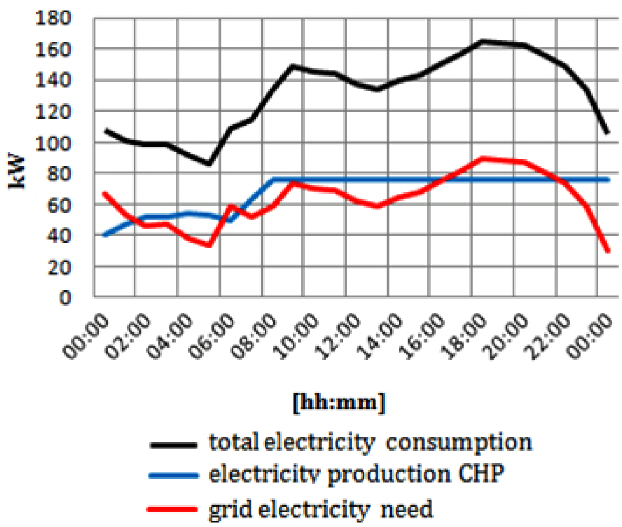

Figure 3. Expected typical daily electricity flow pattern.

Improvement options (Phase 3)

In order to decrease the simulation time and extensive data output of HOMER, a pre-selection of renewable technology for building application is made.

Considered on site renewable energy technology (RET)

Wind-turbines

The hotel is located in an urban area; hence only rooftop application wind turbines are left as a realistic option. In this research, a 5 kW rooftop wind-turbine is evaluated.

PV panels

The most common RET on site or nearby is PV. The free space at the roof of the hotel forms a potential surface of 240 m² for PV panels. As there are more options for PV panels considered in this research, the roof top PV panels will be addressed as 'roof PV'. Another potential surface for installing PV panels is the south-façade of the hotel, where the hotel from the 7th floor will be free from shading by neighbor buildings. A potential vertical PV area 530m² is taken into consideration, further addressed as *'façade PV'*. The third possibility for installing PV is found in placing PV panels at one of the neighbor buildings, addressed as 'nearby PV', in return for a monthly rent price. This increases the potential surface area for PV panels significantly.

Storage

HOMER automatically determines the most feasible storage capacity for the surplus of electricity production by renewables, or to sell the electricity back to the grid. Batteries are considered as apossible storage medium, and is automatically sized by HOMER.

HOMER input

The expected real discount rate considered in the HOMER simulations is 3.43% and is calculated by equation 2:

$$i = \frac{i' - f}{1 + f} \qquad \text{(eq.2)} \quad [4]$$

Where:
i =real discount rate;
i' = nominal discount rate (=5.5%);
f = inflation rate (=2%)[12,13].

An overview of all RET options, including sizes, evaluated in this research are shown in **Table 3**. HOMER evaluates all possible combinations of configurations of the given options.

Weather conditions

Annual weather conditions at the location of Amsterdam as wind speed and irradiation are obtained from the NASA Surface Meteorology and Solar Energy website [14].

Results and discussion

HOMER scales the RET improvement options, as is shown in **Table 3**, on the basis of Renewable Fraction (RF, percentage of consumed electricity coming from on-site RET) and Life Cycle Cost (LCC). Scatterplots show the relation between RF and dLCC (difference in Life Cycle Cost) for every possible configuration. The

Table 3. RET improvement options.

RET options	Options on size and unit numbers	Price
Wind-turbine	0 or 1 wind-turbines	28.500€ incl. installation
Roof PV	0, 120, 240 m²	311 €/m²
Façade PV	0, 265, 530 m²	334 €/m²
Nearby PV	0, 500, 1000, 2000 m²	236 €/m²
Battery	50.000 kWh	1.000 €/unit numberb
Converter	Automatically sized by HOMER	900 €/kWb
Grid		€0,112a

[a] Considered is €100/MWh according to the commodity prices, adding a price of €11,80 of taxes/MWh and energy escalation rate of 2% [16,17].

[b] Unit price in HOMER.

dLCC of the configuration without any RET improvement options (base-case) is considered to be € 0,00.

Figure 4 shows the results of all combinations of the three possible variations of PV-packages, when **no roof rental cost** is considered. Groups of same sized nearby PV surface area are circled, and their size is addressed above. The groups of same sized façade PV packages can be identified by their color: black refers to 0 m² façade PV, orange refers to 265 m² façade PV and blue refers to 530 m² façade PV. Groups of same sized roof PV can be identified by the shape of the figure: a circle refers to 0 m² roof PV, a triangle refers to 120 m² roof PV and a cross refers to 240 m² roof PV. A low dLCC and a high RF is most preferable and the package with the lowest dLCC is the cost optimal. The façade PV (comparing colors) leads to an increase of both dLCC and RF. From economical point of view, it can be concluded that façade PV is not unfeasible. The roof PV (comparing shape) results, especially in the lower PV surface areas, in a decreased dLCC and an increased RF, which makes these packages both economically and environmentally feasible. The nearby PV packages cannot be analysed due to the absence of roof rental cost.

Figure 5 shows all possible RET improvement options, including the possibility of a rooftop wind-turbine. Black dots refer to a configuration without a wind-turbine and blue dots to configurations with wind-turbine. In the situation of the base-case, adding a wind-turbine to the to the current energy supply system leads to an expected contribution of € 10.435 in LCC and 2.7% in renewable fraction. The contribution of the wind turbine to the LCC has in every PV package

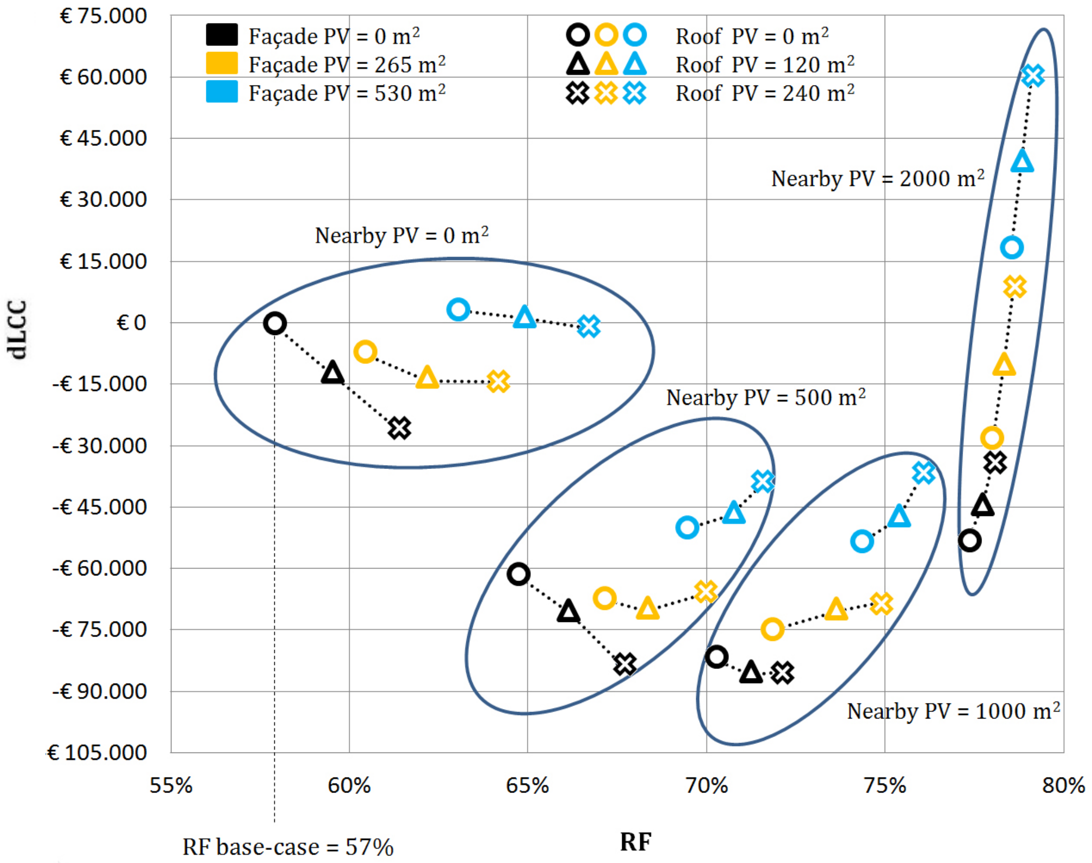

Figure 4. Scatter plot for all PV-packages for without roof rental cost.

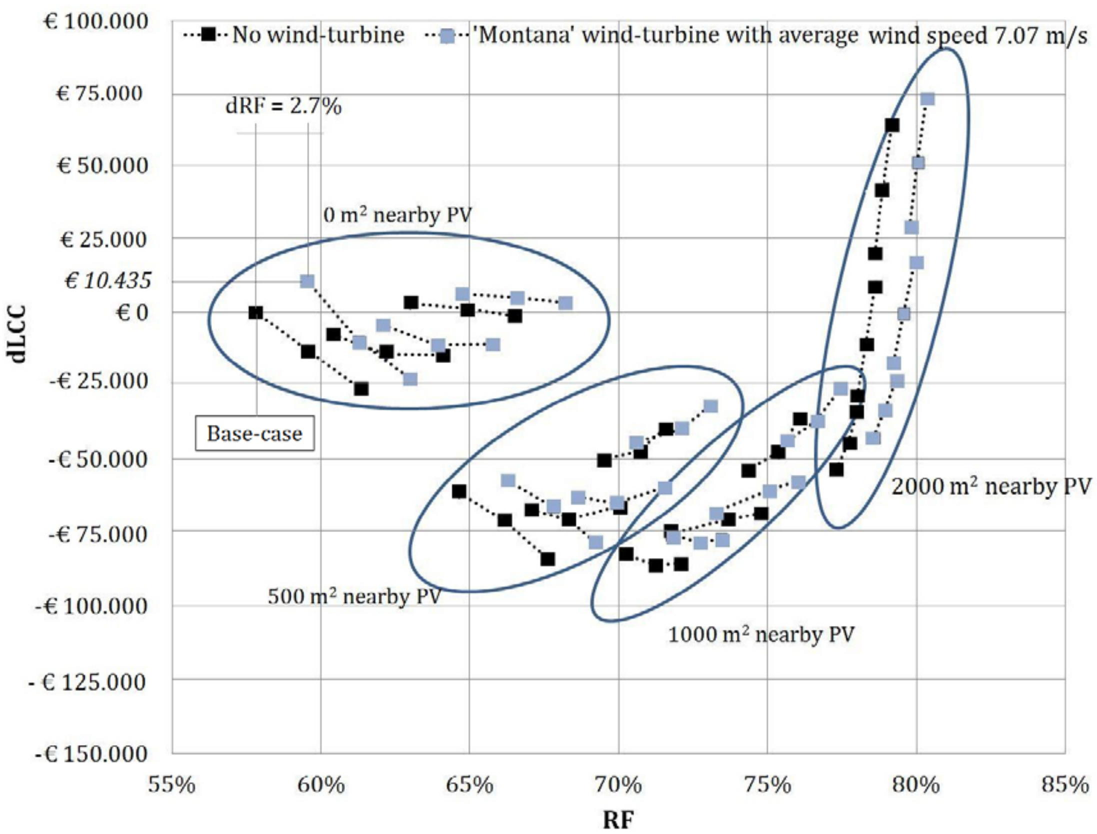

Figure 5. Scatter plot of all PV packages with and without wind turbine and without roof rental cost.

approximately the same magnitude, which makes it under the current circumstances economically unfeasible to add a rooftop wind-turbine at the hotel and just small increase of RF in return.

Figure 6 includes all PV packages as shown in **Figure 4**, but includes roof rental cost of 5 €/m² in the nearby PV option, the PV installed on a neighbour building. The groups of packages with nearby PV increased in dLCC and significantly changed the expected economical performance. Achieving a RF of above 75% with PV panels appears to be difficult and goes along with a rapid growing dLCC. Out of **Figure 6**, 5 optimal packages are selected:

1: Cost optimal in case of no nearby PV;
2: Cost optimal in case of nearby PV only;
3: Overall cost optimal solution; Cost optimal solution in case all considered renewable energy packages are taken into account.
4: Preferable solution; higher RF (+12.8%);
5: Preferable solution; higher RF (+14.9%);

The optimal packages 4 and 5 expect smaller profit compared to the cost optimal solution, however show a larger increase of RF, which could be important to meet potentially increasing LEED requirements in the future.

Conclusions

The study shows that applying the current design of the energy system of the hotel in Amsterdam can be further improved by applying PV on the façade, roof and on the roof of a neighbor building. The cost optimality analysis results in five optimal packages and are shown in **Figure 6**. Optimal package 3 with 500 m² nearby PV and 240 m² roof PV is the cost optimal solution, leading to a difference in LCC of -€ 41.452 and contributes for 10.5% to the RF.

Installing PV panels on the rooftop of the hotel appears to be profitable. However, the small available surface area leads to a maximum increase of RF of 4,5%. Renting a roof top of a neighbor building could be used for a more significant increase of the RF and is in case roof rental costs of 5 €/m² even profitable until ±1000 m². Achieving a RF of above 75% requires a large PV area, and goes along with an increasing LCC.

The installation of a rooftop wind-turbine is not profitable and only leads to a small increase in RF, as shown in **Figure 5.** ■

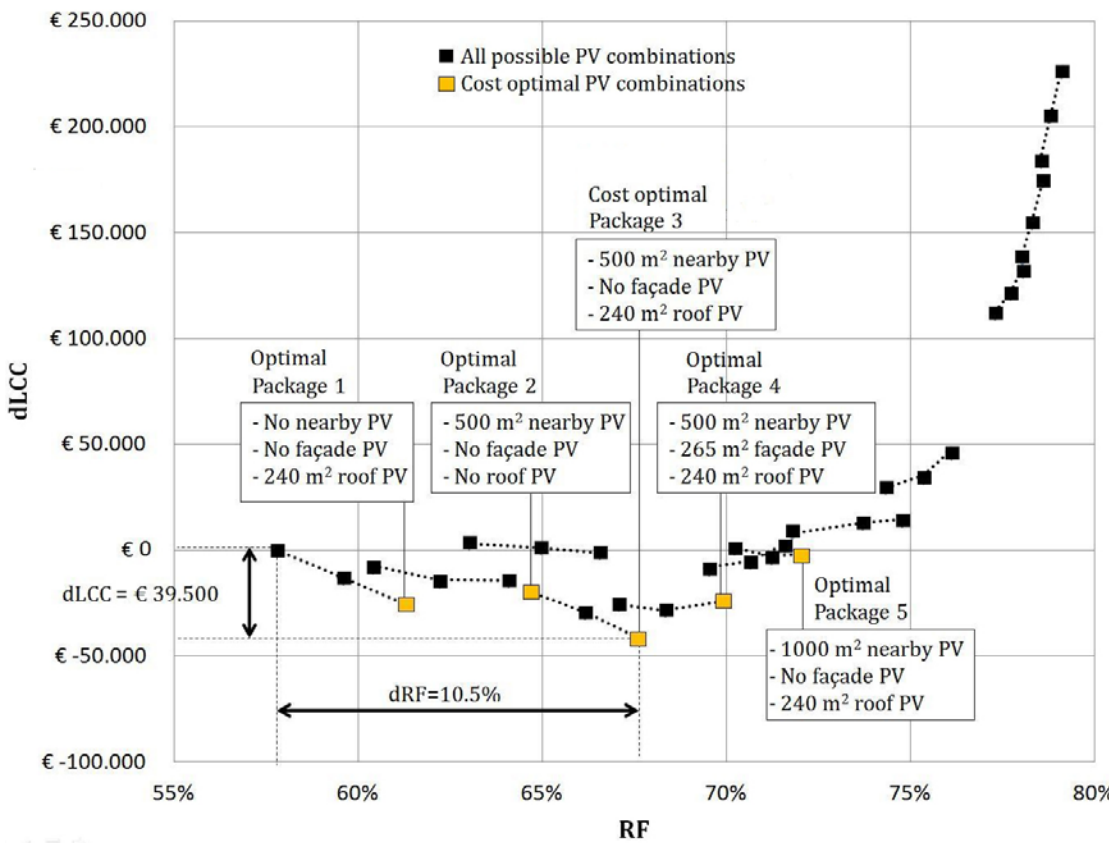

Figure 6. Scatter plot of all PV packages including 5 €/m² roof rental cost for nearby PV and the 5 optimal PV packages.

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Summary of the PhD Thesis of Atze Boerstra

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Atze Boerstra, Vice President of REHVA, defended on September 8th 2016 with great success his thesis "Personal Control over Indoor Climate, Impact on Comfort, Health and Productivity".

How does having or not having control over one's indoor climate affect office workers? It was this question that triggered Atze's PhD study. The central aim of the study was to investigate the mechanisms behind availability and (objective and perceived) quality of indoor climate control devices, and to explore the impact of control on comfort, health and performance of office building users. A first result of the study, was a conceptual model that describes the core variables at hand and their interrelationships. The central assumption that underlies the model is that human responses to sensory stimuli are modified when those exposed have control over these stimuli. This implies that it is not just the objectively measured indoor climate that affects whether people feel warm or cold, or experience olfactory discomfort. Instead the idea is that personal control (availability of adaptive opportunities) also has an impact and in fact acts as a moderator.

Background

Office workers often have no or limited possibilities at their workplace to control their indoor climate. They nowadays frequently are exposed to environments deprived of operable windows, adjustable thermostats and other opportunities to fine-tune their local air quality and personal thermal environment according to momentary needs. When office buildings are (re) designed personal control over indoor climate and adjustability of facades and HVAC systems are apparently not always high on the agenda. This probably is due to a lack of knowledge in terms of personal control related mechanisms amongst relevant decision makers (principals, architects, consultants etc.) and amongst building scientists in general.

Study objectives

How does having or not having control over one's indoor climate affect the average office worker? What is the impact of perceived and exercised control on general satisfaction with the work environment and, for example, thermal and olfactory comfort? To what extent can the incidence of building related (sick building) symptoms be influenced by introduction of optimal control options? And how is individual task performance affected by adjustable and responsive heating, cooling and ventilation systems? It was these kind of questions that triggered the PhD study presented in this thesis.

The primary aim of the study was to investigate the mechanisms behind availability and (objective and perceived) quality of indoor climate control devices and the impact of control on comfort, health and task performance of office building users.

The core research objectives were as follows:

1. to examine relationships between availability and quality of HVAC/building related control devices in office buildings and perceived control over the indoor climate;
2. to examine relationships between perceived control over the indoor climate and comfort and satisfaction of office workers;
3. to examine relationships between perceived control over the indoor climate and health of building occupants, specifically the incidence of building related symptoms (SBS);
4. to examine relationships between perceived control over the indoor climate and (self-assessed and objectively measured) performance and (self-assessed) sick leave of office workers.

An additional objective was to compile an inventory of available, exercised and perceived indoor climate control in modern Dutch office buildings.

Conceptual model

A first result of this study was a conceptual model that describes the core variables at hand and their interrelationships (see **Figure 1**). The core assumption is that it is not just the objectively measurable indoor climate that affects whether people feel warm or cold, or are dissatisfied with indoor air quality. Instead the central idea is that personal control (availability of adaptive opportunities) also has an impact and in fact acts as an interactive variable. Human responses to sensory stimuli like elevated temperatures or suboptimal indoor air are assumed to be modified when those exposed have control over these stimuli.

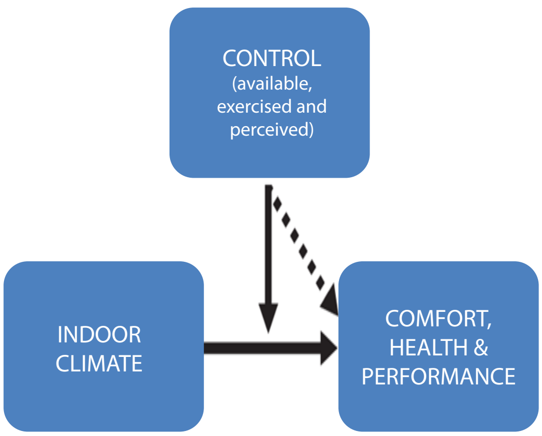

Figure 1. Variables & relations studied

This model was constructed after an analysis of existing related models as found in the literature. Specifically models that acknowledge man-environment interactions, occupant behaviour and adaptation were evaluated.

Methodology

The conceptual model was further explored through:

– a (re)analysis of a historical database;
– a field study in 9 Dutch office buildings, and:
– a laboratory-intervention study (conducted in co-operation with the Danish Technical University).

The database research step involved analysing data from 1612 occupants working in 21 Dutch office buildings (BBA database). This database was selected as it contained information on building characteristics, questionnaire data related to available and perceived control, comfort perceptions and SBS symptom incidence. The data were explored using a multilevel modelling strategy with occupants nested within buildings. In four separate models it was tested whether personal control scores were related to comfort, symptom incidence, productivity and sick leave scores (the 4 outcome parameters studied).

The database analyses outcomes were used to design a field study. The field study was performed during the winter of 2011/2012 in 9 modern Dutch office buildings and involved inspection of relevant building and building service system characteristics (including presence of operable windows, adjustable thermostats and other controls) and indoor climate measurements. In these 9 buildings, a total of 236 office workers agreed to participate in a questionnaire and a subgroup of 161 were also interviewed. The questionnaire contained general questions related to respondents' thermal and olfactory comfort and also asked about building related symptoms, comfort perceptions, self-assessed productivity and self-reported sick leave. Furthermore, people were asked about perceived control and control use (exercised control). The indoor climate measurements included thermostat effectiveness measurements with control adjustments done by the research team, that helped to objectify how ‘fast’ the available temperature controls are during the heating season. First, standard tests were used to explore relations between available, exercised and perceived control. Next the field study data were analysed using a multilevel strategy to find out what building, installation and organizational factors determine perceived control over one indoor climate.

Multilevel analysis techniques too were used to investigate correlations between combined perceived control over temperature and ventilation on the one hand and comfort-, satisfaction-, building symptom and productivity-indices on the other hand. Next a laboratory study was conducted to further investigate how having or not having control, specifically over the thermal environment, affects human responses to the indoor environment. This study was conducted during summer in a field laboratory that was kept at a constant temperature of 28°C. During the first session of 2.5 hours (A) subjects were able to fine-tune their local thermal environment at any given time with a personal desk fan with continuous, adjustable control. During the second session (B) subjects still had the desk fans, but this time the fans were controlled from an adjacent room by researchers who adjusted the individual air velocity profiles so they were identical to those recorded during the first session. Thus, each subject was exposed to two customized conditions with identical exposure, only different from a psychological point of view. During the two sessions identical questionnaires and performance tests were used to evaluate subjects' comfort, SBS symptom incidence and task performance.

Database & field study results

The database analysis revealed a significant association between personal control (an aggregated 5-point control index) and 4 outcome parameters (in all cases with a p-value of 0.001 or lower). Higher control scores were systematically associated with higher comfort scores, lower symptom incidence, higher productivity scores and lower sick leave effects. The results imply that when building occupants are provided with effective operable windows and effective adjustable thermostats, they generally will be more comfortable and more productive (at least according to their own estimations). They will also experience less sick building symptoms and will report in sick less often due to an inadequate indoor climate.

The field study results implied that just about 1 out of 3 Dutch office workers are satisfied with the amount of indoor climate control at their workplace. Mean score for perceived control over temperature in winter, over temperature in summer and over ventilation (in general) was around 3 on a 7-point scale (with 1 = no control at all, 7 = full control). The scores were considerably lower than those for perceived control over sun penetration and perceived control over light. The number of colleagues one shares the workplace with has a considerable effect: more officemates means a lower level of perceived control over one's indoor climate. Also men and those with workstations further away from the facade have a significantly lower level of perceived control.

The majority of the Dutch respondents turned out to have access to both an adjustable thermostat and an operable window. And more than 80% of the respondents indicated not to take energy use effects into account when using their controls. As far as exercised control is concerned, according to the office workers themselves, the use of adjustable thermostats is less frequent than that of operable windows, especially in winter. Also, winter adaptation by clothing adjustment turned out to be more popular than thermostat use. Frequency of use of controls showed to be linked to perceived control over indoor climate. For example, those respondents that used their adjustable thermostats less frequently than monthly, or never, score significantly lower on perceived control over temperature in winter than those that used them monthly, or more often.

The results of the thermostat effectiveness measurements in the 9 buildings allowed for a quantitative estimation of available control over temperature during the heating season. The different buildings and their heating systems showed large variation in thermostat effectiveness. Measured average of speed' differed between buildings from +0.2 to +2.5 K/h for upward interventions. Upward adjustments of thermostats in winter were found to be more effective than downward adjustments in winter. A strong correlation was found between measured thermostat speed in heating mode and average thermostat speed as perceived by the occupants during winter.

The field study analysis revealed that access to operable windows and not experiencing organisational bans on use of controls (use of thermostats, operable windows etc.) are two factors that have a positive and significant effect on perceived control over the indoor climate. Further analysis of the field study data showed positive and significant associations between perceived control and comfort perception, overall satisfaction with the indoor climate and self-assessed productivity (in all 3 cases with p-values of 0.001 or lower). No correlation was found between perceived control and the incidence of building related symptoms. The field study results imply that perceived control over indoor climate in office buildings can be elevated by providing access to operable windows and by not banning building occupants from control use. The results furthermore imply that buildings that are designed for a high amount of perceived control over the indoor climate will have more comfortable and more satisfied occupants. They furthermore will have occupants that estimate themselves to be more productive.

Lab study results

Then, as far as the laboratory study is concerned: perceived control over temperature, air velocity, ventilation etc. was significantly higher during session A (the with-control situation), but there were no differences in perceived comfort and SBS symptom intensity. About two-thirds of the subjects indicated a preference for the situation as during the first session when they themselves controlled the air movement. Surprisingly, self-assessed performance during session B (the no-control situation) was significantly higher than during session A. On the applied 7-point scale that went from 1 = –30% to 7 = +30%, self-estimated performance increased by 4.2%-points from session A to B. Also objectively measured performance was significantly higher during session B, specifically for number addition and multiplication tests (performance differences were respectively 10.4%-point and 8.2%-point). A further analysis indicated that this task performance effect probably can be explained with the cognitive load theory. This theory assumes that the working memory of the human brain has limited capacity and can be overloaded when involved in too many (complex) tasks.

Conclusions

The combined outcomes of the database analysis, the field study and the laboratory study support the hypothesis that control (having or not having control) over one indoor climate alters one's reactions to that indoor climate. The mechanism involved was not totally explained but, overall, the combined studies imply that investing in effective and usable indoor climate controls will enhance perceived control over the indoor climate. Enhanced perceived control also improves office workers' satisfaction with their thermal environment and the indoor air quality at their workplace. It also increases overall comfort perceptions. The results related to the productivity effects (both self-assessed and objectively measured productivity effects) were rather inconclusive. Also the results in relation to the incidence of building related (SBS) symptoms were somewhat inconclusive.

As modern office buildings become more and more open plan offices of the future, where workers may not have a fixed designated work station, in many instances, will ask for more than just standard controls like operable windows and adjustable thermostats. Recent developments in the form of personal ventilation systems and local climate control systems integrated in office furniture seem to open up promising alternative routes towards better adjustable indoor climates in offices.

This PhD study revealed that personal control over indoor climate is a complex phenomenon that involves many aspects. The conceptual model was partly validated but some mechanism-related questions remain unanswered. To better understand how office workers use controls and to understand how building occupants' perceptions about their indoor climate are influenced by the presence and use of these controls, it is necessary to look beyond the traditional borders of building science and indoor climate research. Further research is needed in close cooperation with environmental psychologists and other social scientists to explore in more detail how control over one's indoor climate affects comfort, health and task performance. ■

Building solutions for low temperature heat supply

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Key words: domestic hot water preparation, district heating, flat stations, low-temperature district heating

Abstract

When utilizing low-temperature district heating it becomes important to achieve good control at the consumer side to meet the required cooling of the supply. The low supply temperature as such is not a big concern for thermostatic radiator controls. When it comes to the domestic hot water the low supply temperature can cause challenges when it comes to Legionella growth. It is therefore important to apply domestic hot water preparation units that can prepare the hot water with minimized risk of Legionella growth. The best way to avoid Legionella is to minimize the domestic hot water installation volume and prepare the domestic hot water instantaneously when demanded. For single family buildings this can easily be done by right setup of the consumer heating interface and ensuring that the distance between the consumer interface and the point of usage is as small as possible and has less than 3 liters of water volume [1]. When it comes to multifamily buildings it becomes a bit trickier as from historical reason the domestic hot water is typically prepared centrally and then circulated around the building. The temperature of the circulation is then controlled to keep a minimum of 50-55°C, to prevent Legionella growth. This way of domestic hot water preparation puts a limit on how low supply temperature can be used by the district heating scheme or alternatively by other decentralized heat sources. To be able to reduce the supply temperature as much as possible it becomes a necessity to move the domestic hot water preparation in multifamily buildings as close to the point of use as possible. This can be achieved by applying flat stations at each flat [2]. The domestic hot water preparation is then moved from the basement to the flat station at each flat.

Introduction

District energy has for the last couple of years been receiving increased awareness in energy strategy plans of governments and cities and is seen as one of the key drivers for reducing CO_2 emissions by opening up for large-scale application of renewable heat sources. When looking on the generations of district heating (DH) it is clear that the supply temperature has been continuously decreasing [3]. With the increased share of energy efficient buildings the trend is becoming a must to ensure cost efficiency of the DH systems. Lower supply temperature means not only reduced heat loss from the DH network but also higher efficiency of the applied heat source and easier exploitation of low-grade renewable sources. It is therefore clear that low supply temperature gives both better economy and increased options for utilization of low-grade waste heat.

Although reduced supply temperatures have positive results on the energy efficiency of the heat generation process and the distribution there is another factor that needs to be considered, the heat delivery at the buildings. Traditionally the heating installations have been designed according to current norms. This generally means that the older the building is the higher supply temperature the heat emitters were designed for. This causes potential mismatch between low-temperature district heating (LTDH) and installed heat emitters in the buildings. However, this potential mismatch between LTDH and building heat installation design parameters are only applicable at a part of the heating season, most of the time it should be possible to fulfill the building heat demand using low temperature supply.

Consumer interface principles

In general, there are three connection principles for connecting the space heating installation with the district heating network, a) indirect connected, b) direct connected with mixing loop and c) direct connected, see **Figures 1 to 3**. For multi-apartment buildings the same principles are applied in the flat stations. If the network pressure is higher than PN10, only indirect connections can be applied.

In general a) is recommended due to hydraulic separation between the district heating network and the space heating installation. If direct connected system is applied the mixing loop is the recommended alternative to the indirect connection. If floor heating is applied, only a) or b) should be used.

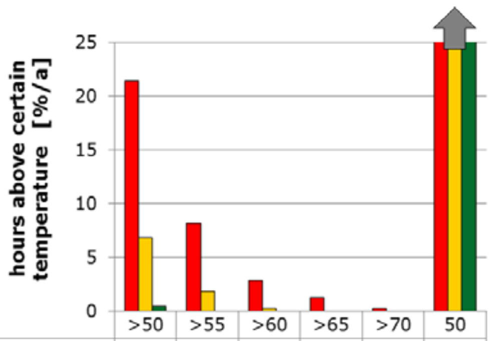
Heat emitters

When it comes to LTDH it becomes important that the space heating system is designed to operate with the low temperature supply. The heat emitting units in the buildings can be floor heating or radiators. Floor heating generally require temperatures less than 40°C, due to their large heating surfaces. Radiators however require higher supply temperatures, due to their small heating surfaces, to fulfill the heating demand. This means that floor heating systems fulfill the requirements set by LTDH and therefore from this point forward only radiators are considered.

Radiators

Studies have shown that radiators in existing houses, from 1970s, have traditionally been oversized and can operate with low supply temperatures large part of the year and almost fully with only small building energy renovations [4].

Even in non-renovated buildings from 1970's, the heating system can operate with supply temperature as low as 50°C almost 79% of the year and rarely needs supply temperatures higher than 60°C (see graph below).



	>50	>55	>60	>65	>70	50
non-renovated 20°C	21,4	8,1	2,9	1,3	0,2	78,6
new windows 20°C	6,8	1,8	0,2	0,0	0,0	93,2
extensive renovation 20°C	0,4	0,0	0,0	0,0	0,0	99,6

T_{supply} [° C]

Percentage of hours during a year with required supply temperatures to achieve 20°C indoor temperature in typical 1970s building in Denmark.

With only minor renovations, new energy efficient windows, supply temperature of 50°C is sufficient for 93% of the year and higher supply temperatures than 60°C are not needed. In case extensive energy efficiency renovations are either not economically feasible or too complicated, low temperature radiators could be installed, bringing in the potential benefits achieved with low supply temperatures.

Radiator space heating control

Although space heating control when applying LTDH is in general the same as when applying traditional DH there are some points that differentiate. Due to the low supply temperatures it becomes very important to achieve accurate control to limit the flow rate and achieve the design cooling of the supply.

To minimize the risk of overflow in radiators thermostatic radiator valves (TRV) with a pre-setting function should be used. The purpose of the thermostat function is to adjust the flow to achieve the desired room

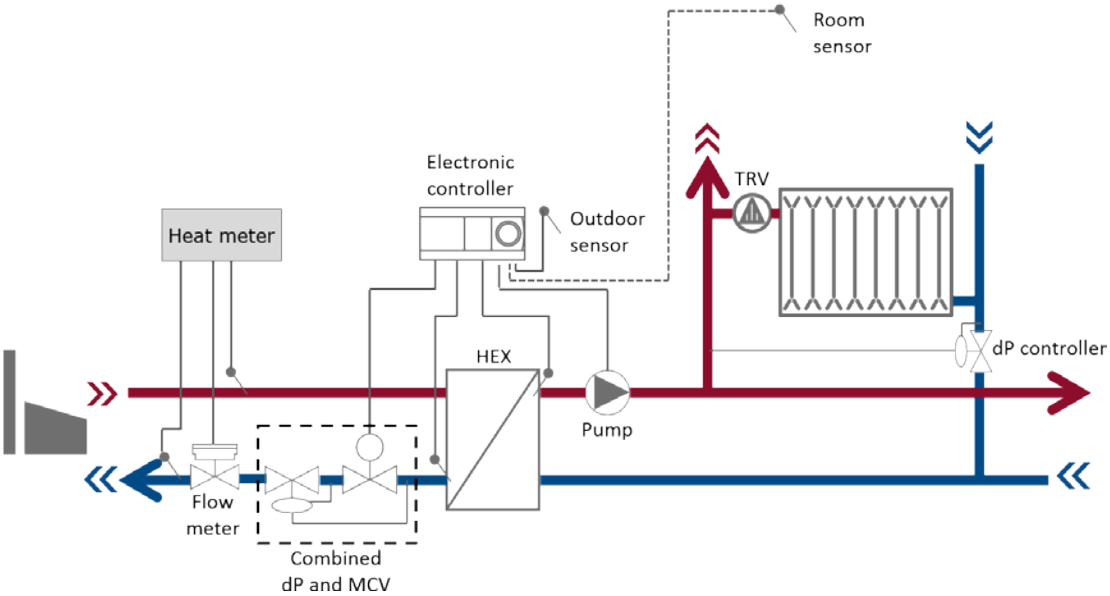


Figure 1. Indirect connected substation.

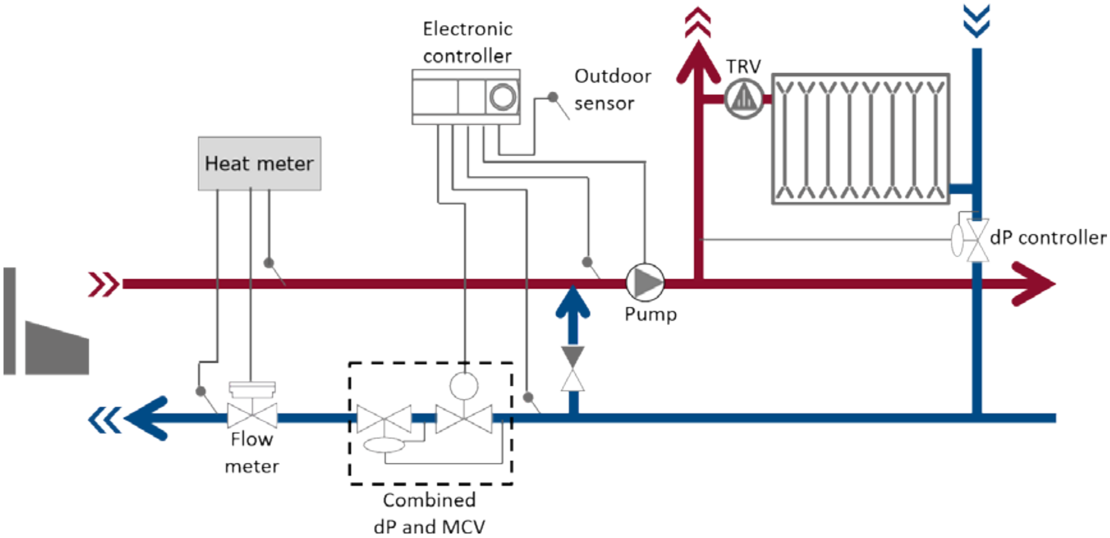


Figure 2. Direct connected substation with a mixing loop.

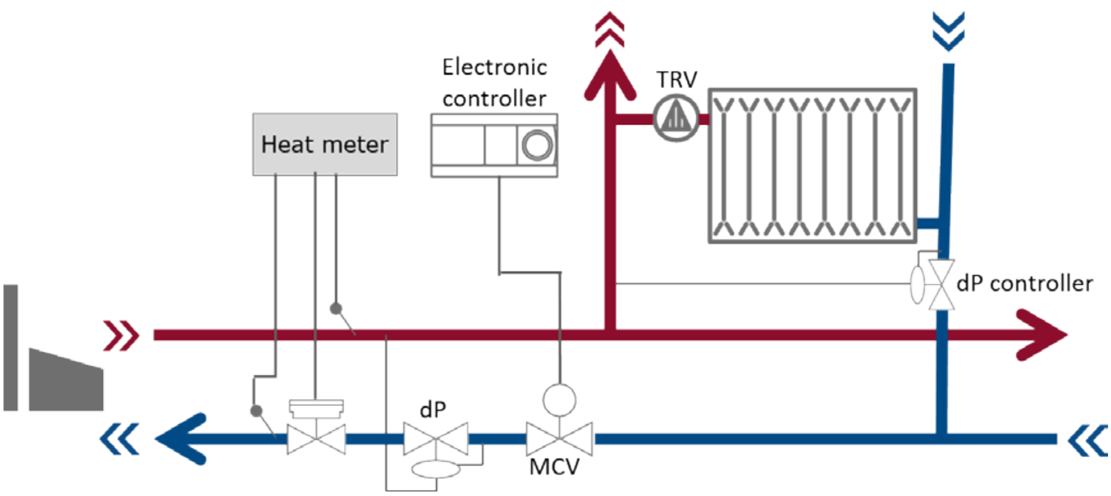


Figure 3. Direct connected substation.

temperature. The purpose of the pre-setting is to limit the maximum flow through the valve to the design demand. Properly set pre-set function will significantly increase the hydraulic balance in the heating loop.

To ensure proper operating condition for the TRV's it is important to install a differential pressure controller. The differential pressure controller will ensure a stable differential pressure at the correct level across the heating installation, typically pr. heating riser of the building.

To limit the impact of wrong setting of the TRV's a return limiter can be installed at the radiator outlets. The purpose of the return limiter is to ensure that a preset return temperature from each radiator is not exceeded.

Domestic hot water systems

When applying LTDH particular focus needs to be put in the DHW interface and the DHW installation. Due to the low supply temperature instantaneous DHW preparation is required along with optimum design of the DHW installation in terms of pipe distances and volume.

For supply temperature above 50°C it is possible to apply instantaneous DHW applications using high efficiency heat exchangers. The recommended DHW control is a proportional flow controller with a differential pressure controller, a temperature sensor and inbuilt idling function. The proportional function of the flow controller will ensure quick initial reaction when taping occurs and that the valve is either fully closed or operating with the idling function when no tapping is occurring. The idling function is a reduced temperature set point when there is no taping. The instantaneous applications can be with or without storage tank. Schematic of an instantaneous DHW application, with and without a thermal storage, can be seen in **figures 4 & 5**.

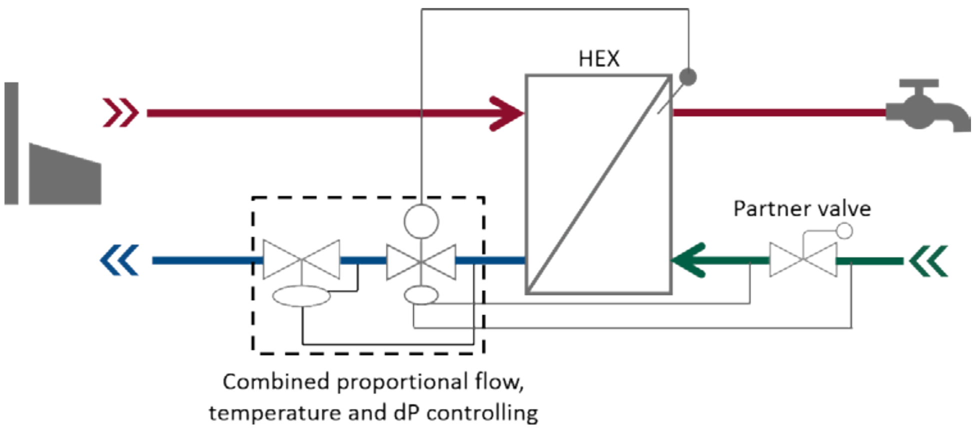


Figure 4. Instantaneous DHW application with a dP controller and thermostatic and proportional DHW controller.

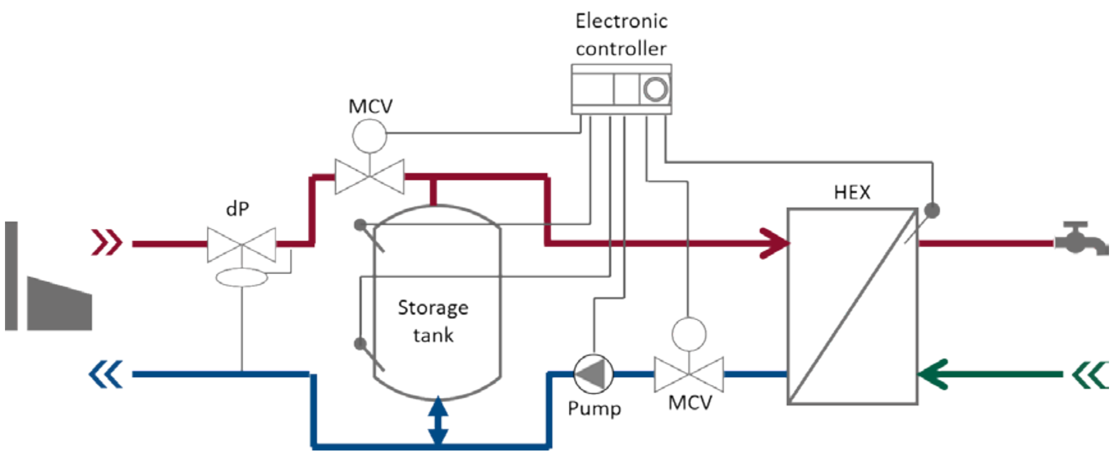


Figure 5. Primary side storage tank and instantaneous DHW preparation.

The difference between the two instantaneous solutions is that if primary side storage tank is applied it is possible to reduce the connection capacity which results in reduced sizes of the service pipes. However, the additional heat loss from the storage tank needs to be considered in connection with the reduced heat loss in the service pipes. Overall the heat loss will in general be lower from the instantaneous solution without the storage tank and the comfort will be higher.

Idling functions

An important factor when it comes to DHW preparation is to limit the waiting time for the hot water. Commonly applied solutions to limit waiting times are: a) minimize the pipe distances and dimensions from the DHW unit to the taps and b) to keep the supply pipe and in some cases the DHW heat exchanger warm during non-tapping periods by using by-passes.

The DHW unit can be kept warm with a by-pass from the supply pipe to the return pipe, by-pass over the control valve or by applying set-back temperatures at the heat exchanger. **Figures 6–8** show examples of possible by-pass functions.

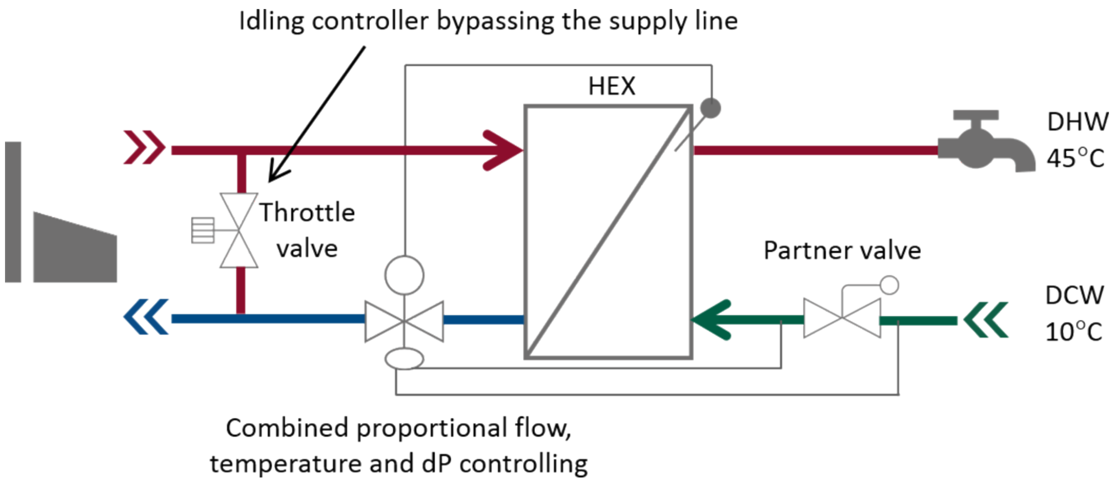


Figure 6. By-pass from the supply to the return line, service pipe kept warm but the heat exchanger kept cold.

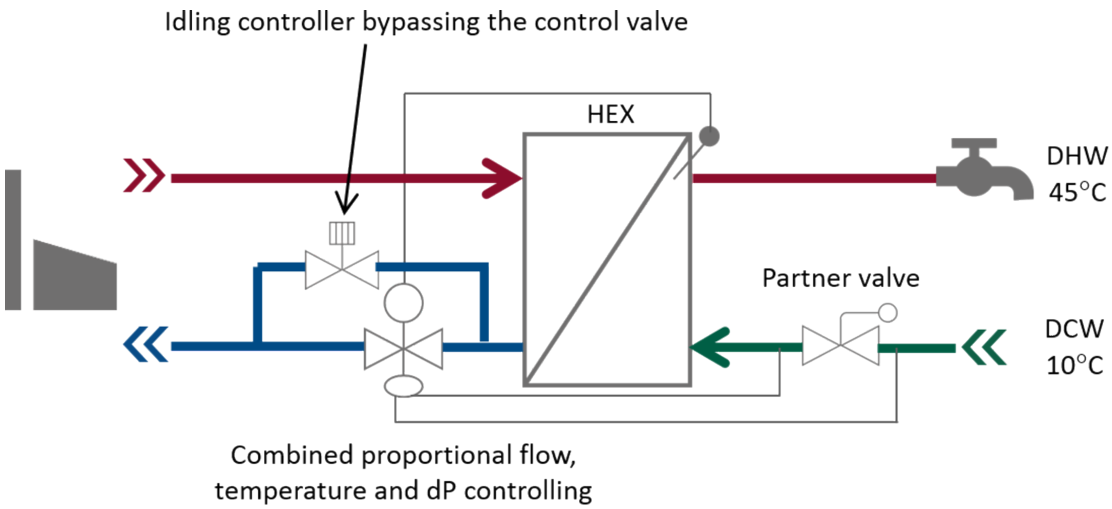


Figure 7. By-pass over the control valve, heat exchanger and service pipe kept warm.

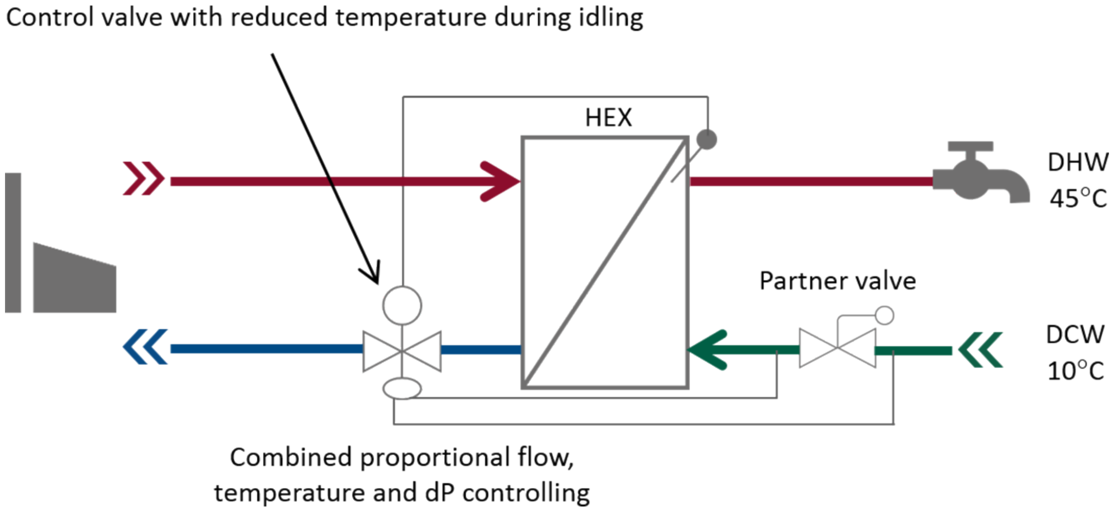


Figure 8. By-pass by applying set-back temperature on the control valve to keep the service pipe and the heat exchanger warm.

The choice of the by-pass function will both impact the waiting time for hot water reaching the tap and the heat loss experienced.

Bacterial concerns

It is well-known that warm water provides favorable conditions for bacterial growth. In hot water systems mainly the Legionella bacteria is considered. Legionella growth is a risk in large volume of standstill water with optimum growth condition at temperatures between 30°C and 45°C.

The approach proposed in relation to LTDH regarding the risk of Legionella is to minimize the DHW installation volume to less than 3 liters and only heat up fresh cold water when taping occurs, i.e. no hot water circulation. With this approach there will be no still standing water as once a taping occurs the existing water volume is completely replaced with new fresh water. In between tapings the hot water in the DHW pipes is allowed to cool down to room temperature.

Conclusions

It is clear that the industry is ready for the 4th generation district heating, low-temperature district heating, and all the necessary technologies are already available.

For existing district heating systems it is important to start already today to specify high performance control equipment and heat exchangers to facilitate the future transition from their current operation to the 4th generation district heating.

By specifying low temperature district heating supply temperatures significant reduction of the heat loss can be achieved, leading to more efficient distribution. Further benefits of reduced supply temperatures are the increased potential to access local low temperature renewable heat sources and increased efficiency of existing heat sources.

The future of district heating as an energy efficient infrastructure is bright and will without doubt play a vital role towards achieving the ambitious goals of limiting the global climate change from human activities. ■

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Performance improvement in a combined water heater

In numerous energy systems there are discrepancies between energy supply and demand. One such system is the domestic water heater. The water heater utilizes sensible heat storage and if combined with latent heat storage there are benefits to gain, both at an individual and on a system level. This study analyses a domestic water heater combined with a latent heat storage, focusing on the number of phase changing materials.

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The use of hot water

In 2008 Swedish Energy Agency and Statistics Sweden performed a study on hot water use in single-family-households. This study resulted in, among other things, a user profile for hot water use presented in **Figure 1**. The profile shows that the hot water use is relatively constant during a day except for a time period of 15 minutes when 110 litres of hot water is used [1].

This brings us to one of the big energy challenges in today's energy system, to find a sustainable balance between energy supply and demand. Shifting peak load through demand side management would be beneficial for the energy system as this would enable a more even consumption and hence production. This would further come with economical advantages, as the electricity price typically is higher at peak load.

One of the biggest energy consumers in Sweden is space heating including tap water heating, accounting for 25% of the national energy consumption [2]. The tap water heating in Sweden is often conducted through a

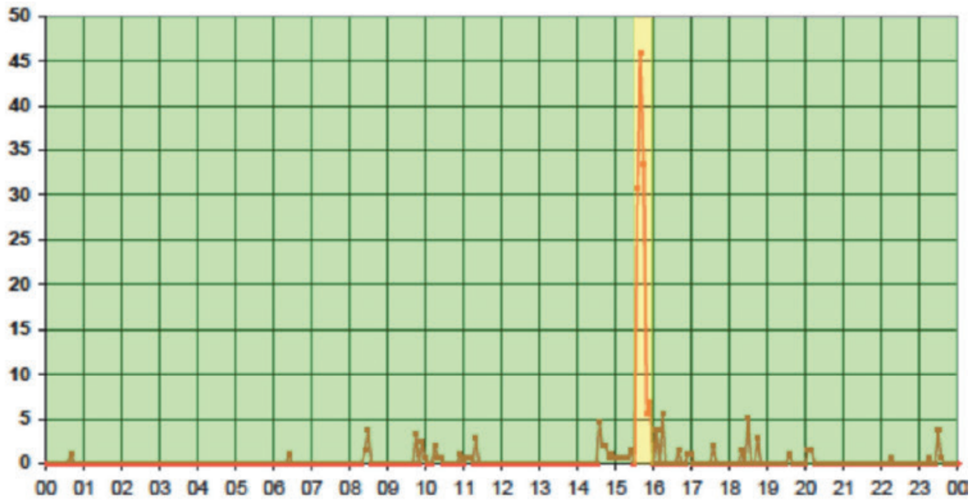

Figure 1. User profile for hot water (Stengård L, Levander T, 2009).

Sensible heat storage
– The storage of thermal energy by changing the temperature of a medium.

Latent heat storage
– The storage of thermal energy by change of physical state of a medium, e.g. liquid to the solid phase.

water heater where the thermal energy is stored through sensible heat storage until demand rises. However, there are several disadvantages with the sensible heat storage such as low energy density. This leads to the requirement of a big water heater to supply enough hot water for a sudden use, e.g. a shower or a bath. A large storage size does also come with higher thermal losses and larger space requirement, which can be undesirable.

A combined water heater

There are room for improvement and development of the widely used domestic water heater that could effect the energy situation both at an individual and on a system level. An opportunity is to combine the water heater's sensible heat storage with latent heat storage. The latent heat storage is considered to be a more efficient and compact storage method. For example, the phase change of water from solid to liquid require the equal amount of energy as heating water of the same mass from 0° C to 80°C.

The market offers a wide range of material for latent heat storage application called phase change materials (PCM). These have the advantages of isothermal phase transition, high energy density and can be tailor made for each system to meet the temperature requirements.

The proposed system would ideally consist of a small water heater to meet the average demand during the day combined with a PCM unit to meet the peak load demand. The PCM unit ought to be charged when demand is low and discharged when peak arises to shift peak load.

In practice, hot water from the water heater circulates through the PCM unit melting the PCM during average load. When peak load occurs the water from the traditional water heater will drop in temperature and become cold. Cold water circulates through the PCM unit and thus starting a solidifying process. In this process the PCM will be discharged, transferring stored energy from the PCM to the water and thereby heating the tap water.

Schematics of the described system are presented in **figures 2–4**. Adopting the proposed system would enable the water heater to work at a more constant temperature whilst being able to provide enough hot water at all hours. Thus, a combined water heater will be smaller, have less losses and work at a lower, constant energy rate.

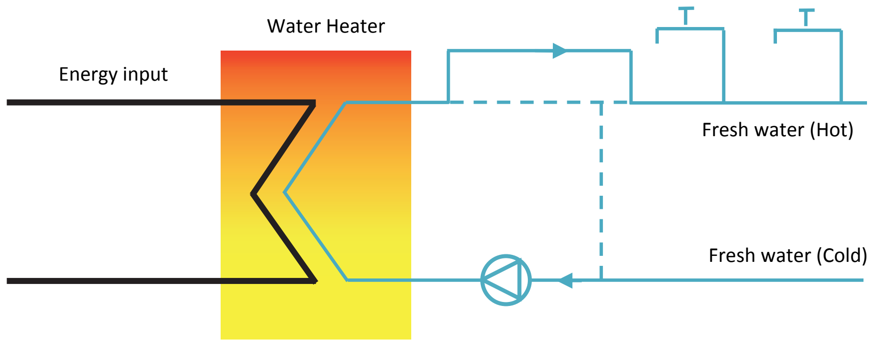

Figure 2. Uncharged PCM.

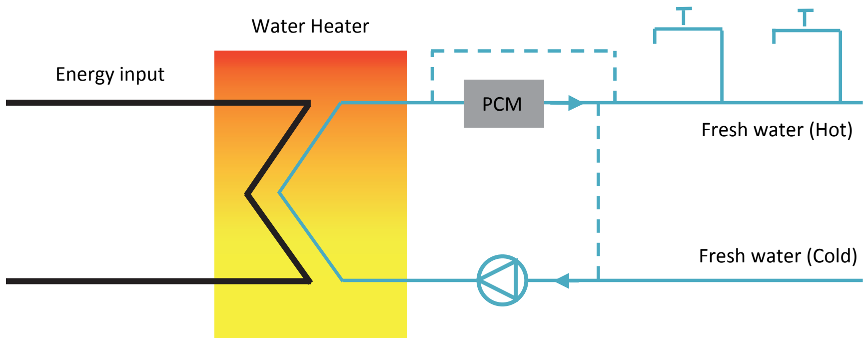

Figure 3. PCM Discharging: Cold water flow through the PCM unit (Fanny Lindberg).

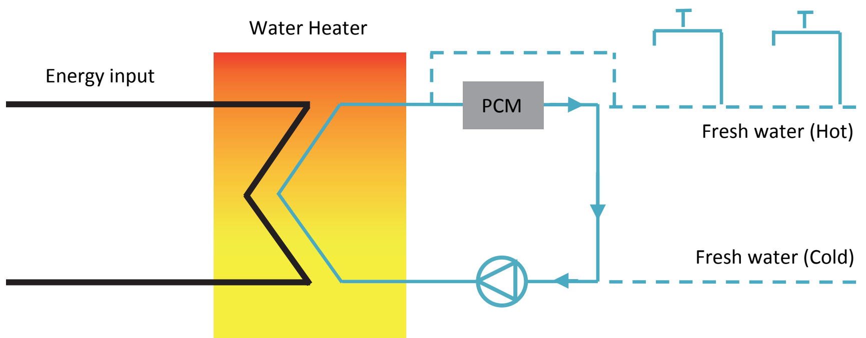

Figure 4. PCM Charging: Hot water from water heater circulates the PCM unit.

Modelling

COMSOL Multiphysics [3] was used to create a model and simulation of the system. The model created is a development of a verified model created by Justin N.W. Chiu and Viktoria Martin in 2013 [4]. The user profile in **Figure 1** formed the basis for the simulation. The green area represents the charging and the yellow the discharging cycle. The system studied is a water heater with a water inlet temperature of 8,6°C [1] and outlet temperature of 61°C [5]. Place note that the aim for the combined water heater is to shift peak load (yellow) to the average load period (green).

Modelling assumptions of materials

- Isotropic properties
- No thermal resistance through surfaces
- Incompressible fluids
- Newtonian fluids
- Adiabatic surfaces facing ambience

The model was created as a finned pipe with two times two storage units for the PCM and is illustrated in **Figure 5**. When analysed, the model is downscaled to a two-dimensional axial symmetric module. The biggest challenge in the development of the model was to create a design with a manageable calculation time, less than 24 h, but with acceptable accuracy.

The finned pipe material was set to aluminium due to good heat exchanging and manufacturing properties. The PCM was set to paraffin. It is interesting to investigate the number of PCM in the energy storage unit and their optimal phase changing temperature. The driving force for heat transfer is proportional to the temperature difference. Therefore, it is advantageous to use PCMs with low phase changing temperature for the charging cycle. The reverse applies for the discharging cycle. Using a combination of PCMs with varying phase changing temperatures preserves the driving force. At the same time the water can reach higher temperatures when discharging and lower when charging. This difference between single and multi PCM systems is presented in **Figure 6a and 6b**. The focus of the study has been to compare PCM units containing one and two PCMs and to find the most advantageous case for the given application.

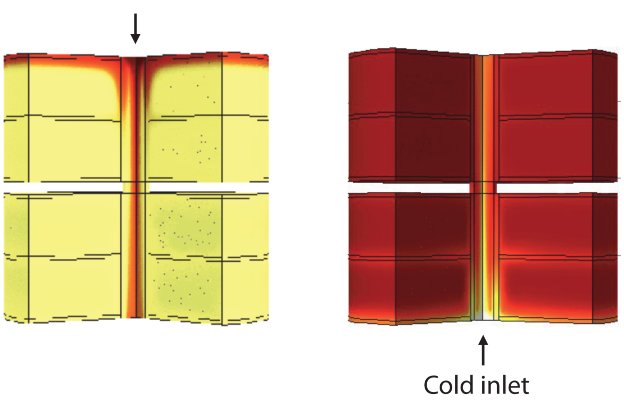

Figure 5. Model in COMSOL Multiphysics.

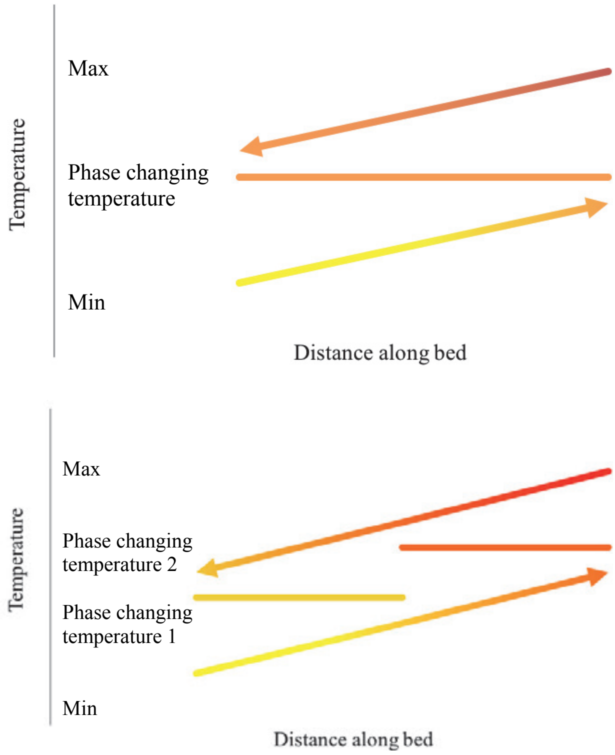

Figure 6a and 6b. Single vs multi PCM heat exchange.

Furthermore, two temperature zones for phase changing temperatures was studied. One higher and one lower. To summarize, four cases were studied for the charging and discharging cycle, respectively. The materials studied in each case are represented in **Table 1**.

Table 1. Material composition for each case.

	One PCM	Two PCM
High phase changing temperature	PCM 50	PCM42 & PCM60
Low phase changing temperature	PCM44	PCM35 & PCM55

Results and conclusions

The results of the simulation are presented as the outlet temperature. The outlet temperature describes the temperature of the water at the outlet of the PCM unit. The outlet temperature of the water during the charging cycle is presented in **Figure 7**. The water temperature at the end of all cases equals the incoming temperature of 61°C. Thus one can make the conclusion that all cases provide a fully uploaded PCM unit. Furthermore, one can conclude that the PCM units holding two PCM materials provide a faster charging as the maximum temperature is reached faster. Hence, the system engineering challenge lies in the discharging cycle.

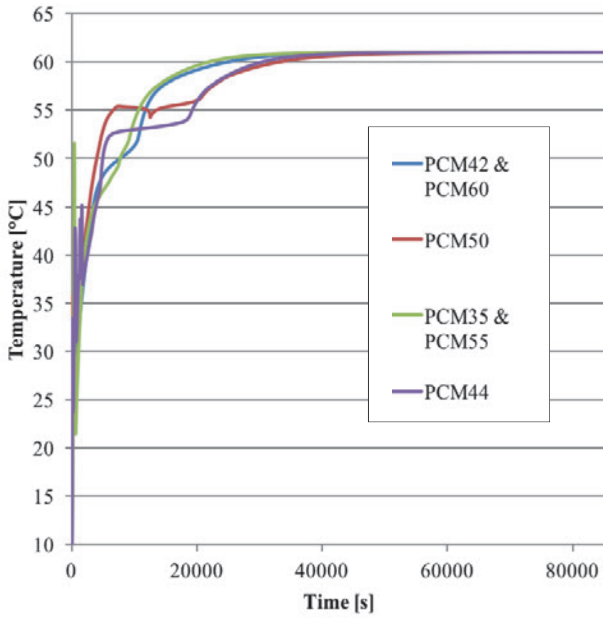

Figure 7. Outlet temperature of water, charging cycle.

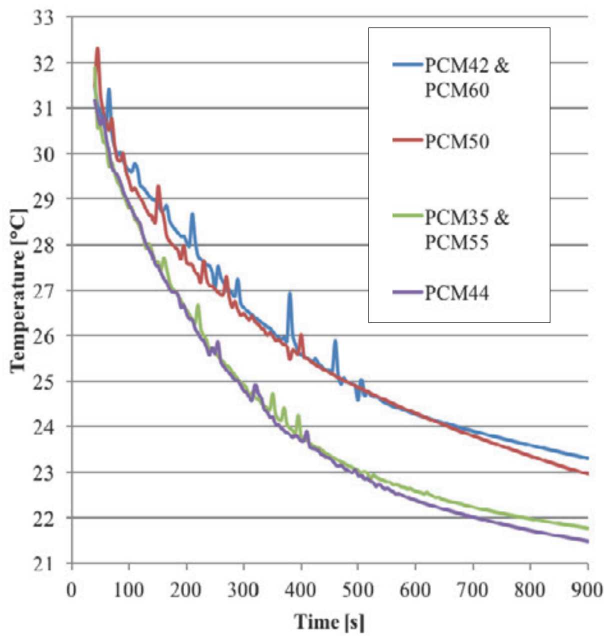

Figure 8. Outlet temperature of water, discharging cycle.

The outlet temperature of the water for the discharging cycle is presented in **Figure 8**. The outlet temperature is lower than the desired one for all cases at all times. However, the inlet temperature is elevated by 15-26°C. Figure 8 presents that the highest outlet temperature is reached for the case of high phase changing temperature and two PCM. The difference between one and two PCM are, however, not significant. To reach an even higher outlet temperature a higher working temperature would be eligible. The system could be further developed if multiple devices were in series or in parallel. This would provide a larger area for heat transfer and a longer contact time which would increase the heat transfer and thus the outlet temperature.

The recommended system for the given application would contain PCM with high phase changing temperature. The charging cycle exhibits full charge for all cases whereas the discharge cycle is critical. For the discharge cycle a sufficiently high outlet temperature is not reached with the developed model. However, a significant rise in temperature from 8.6°C is achieved. The PCM unit with two PCMs provide a slightly higher temperature but more detailed studies of multiple user profiles with a design reassessment should be done to determine which case is most advantageous. It is clear that the system is applicable and feasible in theory, as it allows a shift of the load.

Further studies concerning the possibility of connecting devices in series should be done in order to investigate the circumstances under which higher outlet temperatures can be reached. To summarize, performance improvements can be reached using multi PCM. However, the question whether this is sufficient to outweigh the possible design and construction complications remains. ■

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The ASHRAE Design Guide for Tall, Supertall and Megatall Building Systems

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The ASHRAE Design Guide for Tall, Supertall and Megatall Building Systems was produced in collaboration with the CTBUH. The design guide outlines various tall building mechanical systems that are presently being designed or are planned for the future. Tall commercial buildings in particular present a series of design problems that set them apart from other functions.

The Design Guide will be of interest to owners, architects, structural engineers, mechanical engineers, electrical engineers and other specialized engineers and consultants. This design guide addresses design issues for tall commercial buildings, which are very often mixed-use, and commonly consist of low level retail, office floors, residential units, and hotel uses.

Keywords: Façade, Code Compliance, Energy Efficiency, Climate, Integrated Design.

Introduction

This design guide will be of interest to owners, architects, structural engineers, mechanical engineers, electrical engineers, fire engineers and other specialized engineers and consultants. The design guide not only focuses on the efforts of designers of the heating, ventilating and air-conditioning (HVAC) systems, but also addresses the importance of an integrated design team and their collective efforts and concerns that are the critical elements in determining the ultimate solutions to project needs of a tall building. The guide addresses design issues for tall commercial buildings which are very often mixed use, consisting sometimes of low level retail, office floors, residential floors and hotel floors.

So not only are our tall buildings taller but they have many different functions, each function being specific. The different functions will have different code requirements and with specifics such as life safety we are sometimes going into unknown territory, these items and various additional points will be presented in the design guide.

Architectural Design

This chapter does not include any discussion on the aesthetics of buildings but will discuss possible core layouts and emergency egress routes and refuge floors, from an architectural perspective. Floor efficiencies will also be outlined.

Every building that has been designed and constructed must respond to real estate considerations if the project is to be a successful venture. These considerations include ownership issues as well as matters that are more appropriately a concern of the usage to which the building will be subjected. While of importance in all buildings, these matters are of even greater importance in tall commercial office buildings due to their size and the need for it to meet the additional requirements of its occupants. It is difficult to fundamentally alter a large building, after it is finished and available for use by occupants. So the building usage and performance criteria should be defined at the outset of design. An example of the information that would be included in the detailing of the design criteria for a tall building project is included in the preface.

An initial real estate consideration that must be recognized and dealt with is the nature of the ownership of the building. The ownership entity for whom a building is being constructed falls into several distinct categories, such as owner occupied, speculative leasing, co-op, condo, etc. These categories may overlap but generally they do not. There is often more than a single ownership category and the alternative categories may well affect the design solutions developed for any project.

Many tall commercial office buildings are corporate headquarters developed within a customized program, typically, by the architect and owner with significant input from a real estate consulting firm retained by the owner. The developed program will establish the specific requirements for the design team. For example, will the building contain a data center, if so how large and with what potential for expansion; what dining facilities are to be included; are there executive dining area requirements that are separate from the general employee dining; are the telecommunication requirements and possible technology vendors established; what areas beyond the data center will be operating on an extended time schedule or on a 7 x 24-hour basis? The answer to these and similar programmatic questions will all have a direct impact on the HVAC solutions that will need to be developed for the project, in addition, there are other significant issues which will have a major effect on the final design solution, such as core size, shaft space accommodations, efficiency of floor layouts, multiple mechanical equipment room floors, locations, louvers, etc.

Façade Engineering

This chapter will not cover the structural engineering of a facade but will provide information on interpreting present day energy codes which present some stringent challenges for "tall, supertall and megatall buildings"

A high performance facade design is essential to minimize the solar cooling load and allow for efficient performance of air conditioning systems while enhancing indoor comfort and maintaining views (see **Figure 1**).

The facade should be designed to minimize the solar gain to 10 to 20% of the incident radiation.

Double skin facades achieve flexible operation through a combined system of components which are both known and used already allowing the regulation of heat, cold, light & noise in such a way that comfort is achieved with low energy consumption. Further they also provide an extra level of acoustic insulation and allow natural window ventilation via an intake of air into the cavity between the two layers of the facade - a set-up that can offer the appropriate level security required for night purging in some situations.

Climatic data

The effect of ambient air temperature over the height of buildings, especially super tall and mega tall buildings is presented. The ambient climatic conditions vary with altitude and these changes in ambient conditions can seriously affect load calculations and performance of super and mega tall buildings.

The climate at 100 m above grade is not the same as 600m, examples of the difference in ambient conditions are included in the appendix. However, rarely does the design of upper level of the building capitalize on that difference. Further, wind conditions at the top of a tall building are different. If sufficient data is known about this difference, it can be incorporated into the design.

Stack Effect

The existence of stack effect in tall commercial buildings has often presented major problems (see **Figure 2**). The problems most frequently manifest themselves in a difficulty in getting elevator doors to close and in difficulty in heating lower levels of the building. The elevator doors' failure to close properly is due to the pressure differential across the doors which, in turn, causes the door to bind in its guide way to the degree that the closing mechanism for the elevator doors does not generate sufficient force to overcome the binding effect. The heating problems are due to the substantial influx of cold air through the doors at the entrance level itself and across the outside wall of the building due to the higher permeability of the wall than is the design requirement of the specification for the wall.

Indoor Air Quality and Thermal Comfort

The ventilation requirements for commercial and institutional buildings are given in ASHRAE Standard 62-1. These ventilation rates were chosen to achieve an acceptable level of indoor air quality by control of carbon dioxide, particulates, odors, and other contaminants common to those spaces. If cleaned re-circulated air is used to reduce the indoor air below the recommended values, the Indoor Air Quality Procedure must be used. The requirements are given in terms of cfm of ventilation air per person, or per square foot of floor area.

Thermal comfort

In traditional designs, the HVAC designer's role in achieving comfort conditions often begins and ends at the selection of an indoor design condition and the sizing of the HVAC system to provide these conditions at peak load. The selection of a design dry-bulb condition involves both comfort and cost or energy considerations and can dictate critical design features of the system. For example, some designers may pick a relatively high design cooling condition such as 26°C in order to conserve energy, while others may select one such as 22°C in order to maximize the number of satisfied occupants. Selecting systems and controls that perform efficiently at part load can mitigate the energy downside of the latter.

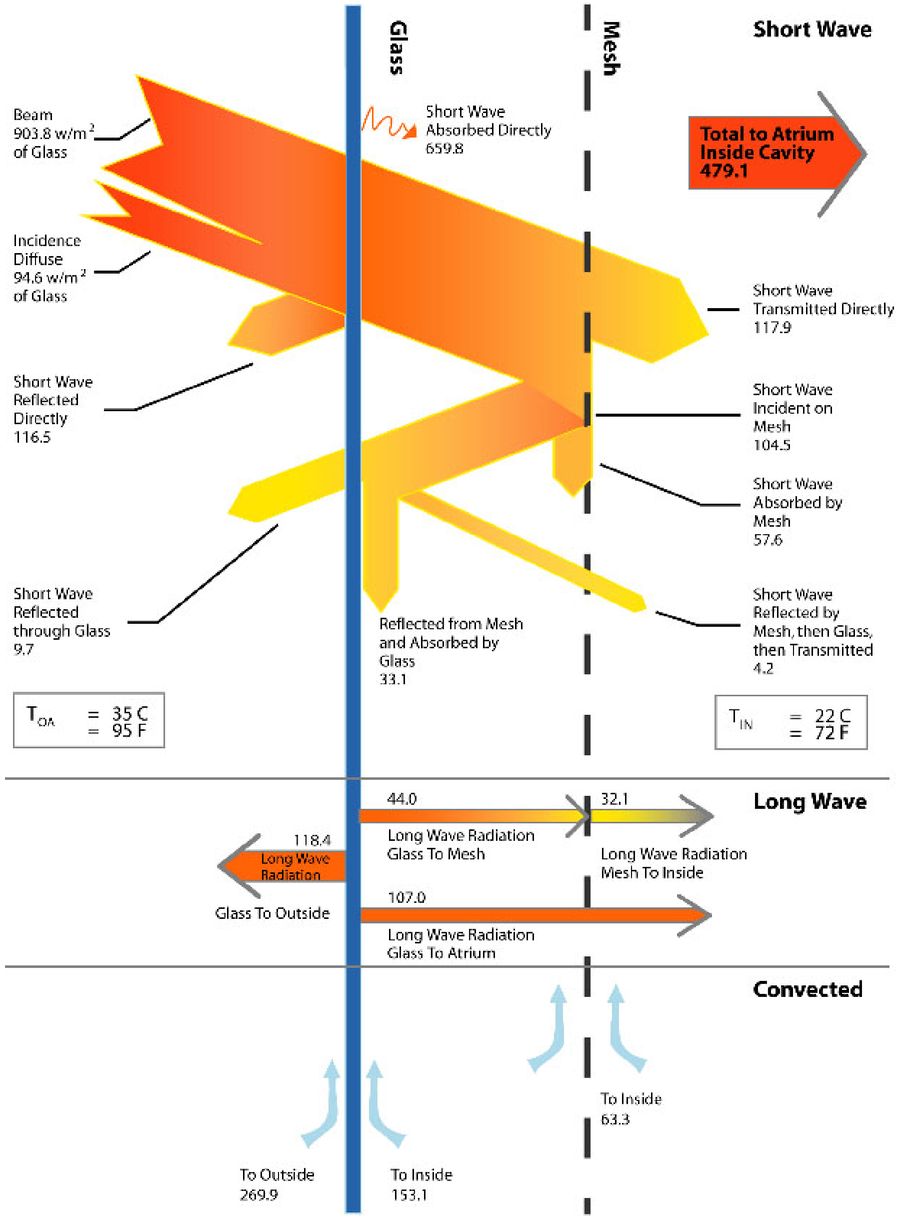

Figure 1. Sankey diagram of a high performance facade construction.
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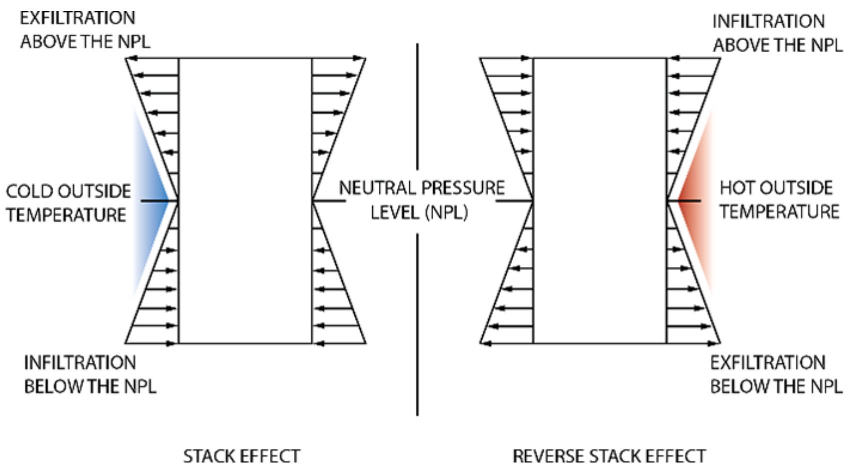

Figure 2. The diagrammatic effects of stack for both summer and winter.
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Thermal conditions indoors, combined with occupant activity and clothing, determine occupant thermal comfort, which in turn impacts occupant productivity and perceptions of air quality. Dry-bulb temperature is only one physical parameter out of many that interact in a complex manner to produce occupant satisfaction.

Thermal conditions affect chemical and biological contaminant levels and/or the intensity of occupants' reactions to these contaminants, but our knowledge of these effects and their mechanisms is very limited. Despite this limited knowledge, achieving high performance in thermal comfort is likely to result in lower contaminant levels and better occupant perceptions of IAQ.

Adaptive comfort

For naturally ventilated buildings and buildings operating in "free-running" mode the indoor comfort temperature was also noted to strongly correlate with the mean monthly temperature outdoors at the time of the survey. This concept suggests that people are able to adapt to the wider range of thermal conditions than is generally considered before. For instance, human can tolerate higher temperature even feel more comfortable when they are under hotter environment. In addition, ASHRAE 55-2013 adapts mean monthly outdoor air temperature to evaluate the indoor comfortable operative temperature.

HVAC systems

The systems that have found application in tall commercial buildings have evolved over the past decades in response to the changes in the perceived goals of the entity that is constructing the building, the expanding needs of the potential occupants be they a corporate end user or a leasing party, and the concerns of the owner with the availability and the cost of energy and the resultant expenditures necessary to operate the building. More recently, the import of environmental concerns, including indoor air quality and the growing challenge to provide safer buildings, has further influenced the approach that is taken in the system selected for a modern tall commercial building.

To meet the challenge of providing systems that address these major issues, the commercially available equipment and the deployment of that equipment have also gone through a period of modification in some design details over the recent past. This process of evolution will undoubtedly continue in the future but the basic general system categories that are available today that are discussed in this chapter will undoubtedly continue to find wide usage in the tall commercial building, such as VAV systems (see **Figure 3**), Fan Coils, Radiant Ceilings, Radiant Floors, Displacement Ventilation and Underfloor Air Distribution It is the technical details of the system design that have been and will be subjected to ongoing modification.

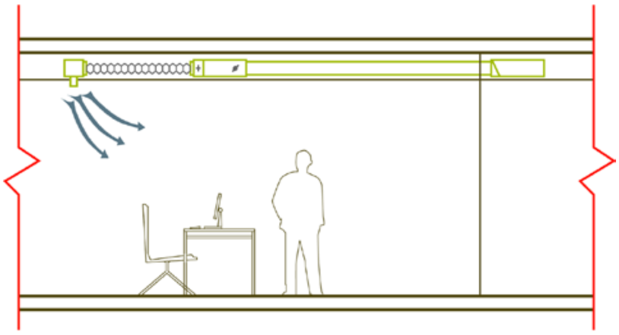

Figure 3. A diagram of a typical overhead VAV system.
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Central Mechanical Rooms and Floor by Floor Fan Rooms

A major decision that must be made by the entire project team in a tall commercial building is whether to meet the project needs for conditioned air through air conditioning supply systems installed in a central mechanical equipment room serving multiple floors or by systems installed in a separate local floor fan room located on each floor supplying air only to the floor on which the system is installed. The choice from any of the two alternative schemes is one of the most fundamental decisions that must be made during the conceptual design phase. It is an issue that concerns the owner, each member of the design team, and the constructing contractors who will erect the building from the completed design documents.

The decision, therefore, is one that requires full consideration and detailed input from the entire project team, including the contractors who will be implementing the project designs. While frequently the decision is predicated on what is being done on competitive projects in the same real estate market and may reflect the bias of one or more of the deciding members of the project team, it is possible to establish points of comparison that can be discussed with relative objectivity to allow the decision to be made in a proper manner.

Central Plants

Typically, tall buildings have central plants in order to increase the efficiency of the cooling and heating systems as well as providing a redundancy of equipment (see **Figure 4**). It is advantageous to situate the chiller plant in a close proximity to an electrical substation. Cooling towers cannot always be situated on a roof 600m above grade, so creative solutions need to be employed. In some cases, air cooled equipment is used and this creates the opportunity of situating air cooled equipment on refuge floors, for instance.

Boiler plants are usually located in basement areas, although many have been installed on roofs or sometimes on refuge floors. However, a solution to the flue exhaust must be found.

Water Distribution Systems

The design of water distribution systems for a commercial tall building differs from the design of these systems for a low-rise building primarily due to the static pressure on the piping system as a result of the height of the building (see **Figure 5**). This condition can affect the design of all of the piping systems in the building, including the domestic water piping and sprinkler systems, but the Design Guide only addresses the chilled water, hot water and condenser water systems.

Energy Modeling and Building Performance

Energy simulation can provide the design team with information regarding the building massing and orientation. In a first concept and it provides clear guidelines as to the massing of the building and the orientation to improve its thermal and natural daylight capabilities.

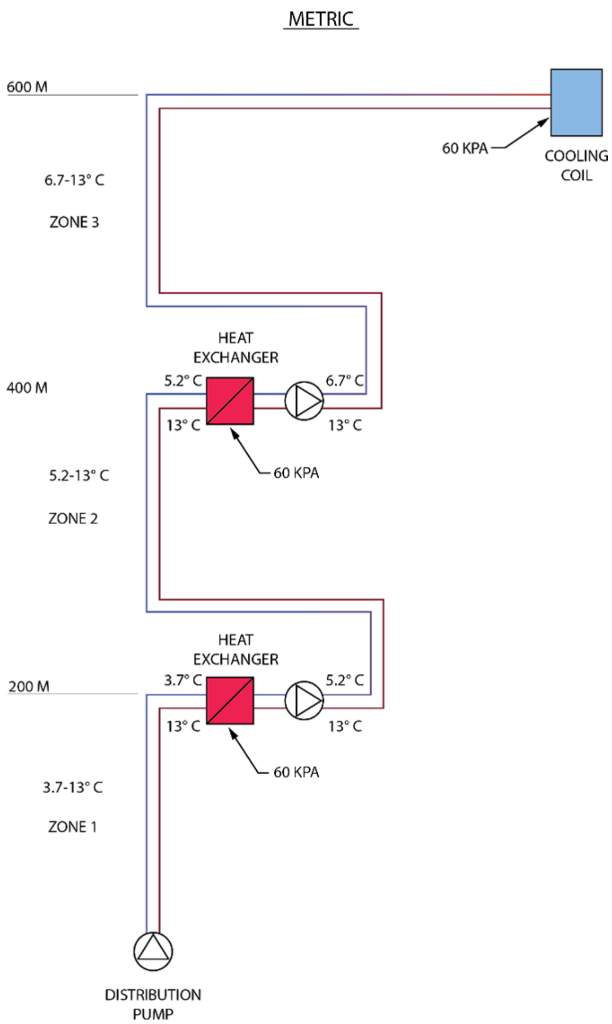

Figure 5. A diagram of a chilled water distribution system for a 600m building where the distribution is split into three parts to regulate static pressure.
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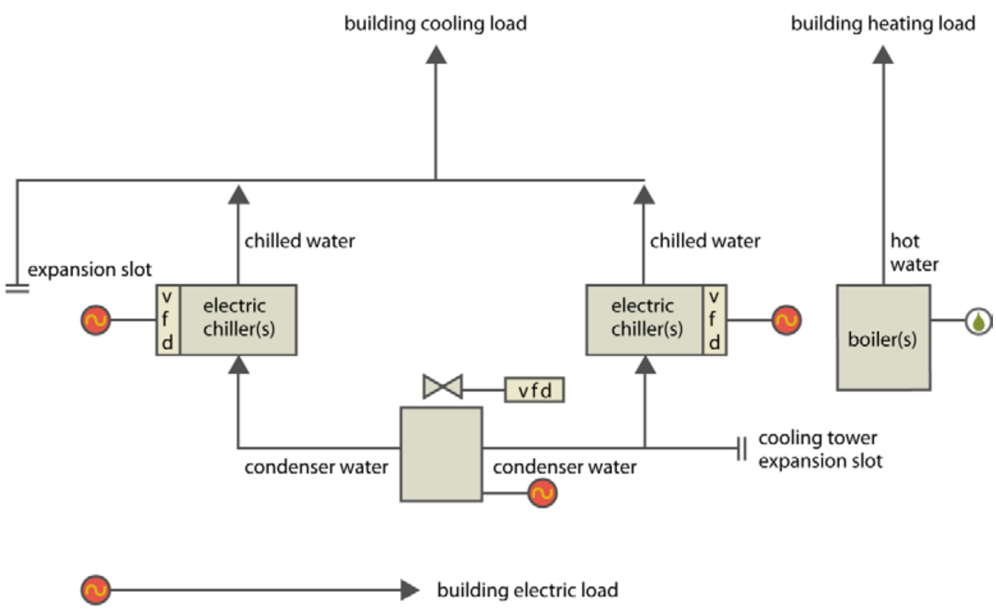

Figure 4. A diagram of a typical central plant for heating and cooling.
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This information would also include information on preliminary energy goals for the building as by ASHRAE 90.1 and other applicable codes, such as China Energy Codes. By setting goals the design team can also outline possibilities in providing efficient building design solutions that consume less carbon than the goals. A preliminary report should include any relevant solutions or possibilities for the building and its systems at the same the report should remove any systems that are not feasible to minimize the alternatives so as not to tax the available budget. With the relevant simulation programs guidance can be provided at any early stage on glass types and systems, for example. The next plan as the project develops is to analyze the buildings performance using simulation programs. Once the base case has been determined energy conservation measures can be assessed. When the base case and alternatives have been developed, probably the most difficult stage emerges, obtaining costs for the different alternative (see **Figure 6**).

At the concept phase it should be possible to define an engineering solution for a building design. The energy consumption of alternatives can be translated into reductions of utility costs and probably more important be translated into reductions of CO_2 consumptions. Carbon trading has begun to emerge although not wholly known by most clients and will continue to develop into energy carbon trading and a reduction of carbon consumption.

Vertical transportation systems

Vertical transportation has improved dramatically in the past 10 years, not only due to the different building types in tall buildings but also lift technology and logistics of people movement. The construction of tall buildings only became possible with the development of the elevator safety braking system and the elevator itself, with the resulting ability to move people expeditiously through the multiple levels of a tall building. Generally, the HVAC designer does not have a significant involvement with the elevators as they are installed in a building other than to provide cooling in the elevator machine room to ensure that the controlling electronics of the elevator system are maintained at an appropriate temperature to allow their reliable operation and, as discussed subsequently in this chapter, if required by code, to vent the elevator shafts and the elevator machine room to atmosphere. In Tall, Supertall, and Mega tall buildings however the final core design generally results in one or more elevators confined within a single shaft. This creates significant problems with respect to "piston effect" caused by the compression of the column of air ahead of the elevator, and "stack effect", either positive or negative, depending on the time of year or climatic conditions of the region.

Plumbing systems

The plumbing systems designed for any building fall into several discrete categories including the domestic water system, which will provide both hot and cold water to various fixtures and water-consuming equipment installed throughout the building; the sanitary system, which will be connected to water closets, lavatories, drains, etc., in the building and will drain the waste from these fixtures to a sewer system external to the building; and a storm water system, which will collect rain water or melted snow and pipe it to an appropriate disposal point, usually a public sewer.

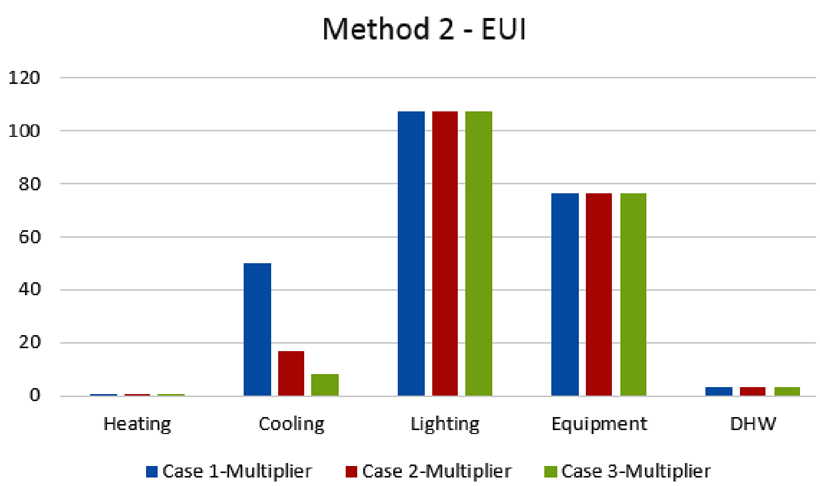

Figure 6. EUI results obtained from an energy simulation comparison.
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Plumbing systems also includes information on traditional plumbing systems but also specifics such as grey and black water systems.

Life safety systems

Every tall commercial building that is constructed should include design details and operating systems that, in total, will constitute a life safety system. The requirements for both the design details and operating systems that should be included will be defined in the building code that applies in the jurisdiction within which the building will be located. The building code should address construction details of the building; should outline minimum criteria for the means of egress from the building in the event of a fire or other emergency; and should specify protective features and systems that must be included to achieve the level of protection that can reasonably be provided to allow adequate egress time and protection for building occupants who may be exposed to a fire or the smoke generated by a fire.

High Rise Residential

High Rise residential faces more scrutiny than a lower-rise development owing to its visibility in the urban landscape. Architectural quality and iconic architecture are often cited as the main contributors to the success of the planning applications. But there are other specifics of residential spaces that need to be resolved, such as:

- Floor plate efficiency: The shape and geometry of other building parts such as offices or hotels, need to be coordinated with residential shapes and areas.
- Conditioning systems. Fan coils (see **Figure 7**) or heat pumps can be employed or other systems such as Radiant floors for heating cooling, active beams or even centralized systems. A solution has to be found for supply and extract riser ducts.
- Many residential spaces can be naturally ventilated. How is this integrated into a mechanical system to become a "mixed mode system"? What about the effect of natural ventilation on the buildings stack effect and what about considerations of the fire department when there are open parts to the building envelope?
- special exhaust systems for washers and dryers
- Differences required for condominiums and apartments
- Electrical metering of each individual unit
- IT and Wi-Fi for all units

Many high rise residences are part of mixed use buildings. The tower may have residential floors, hotel floors, office floors, etc. The core design is very often different for each specific application, also the smoke control is often complicated as occupants do not want to be used by another building use.

Electrical System Interfaces

Typical multi use buildings will have multiple electrical feeds, there will be a normal power supply from the local utility company and an emergency supply from standby generator sets or standby power from batteries. For many modern buildings tenants often require space for their own standby generators.

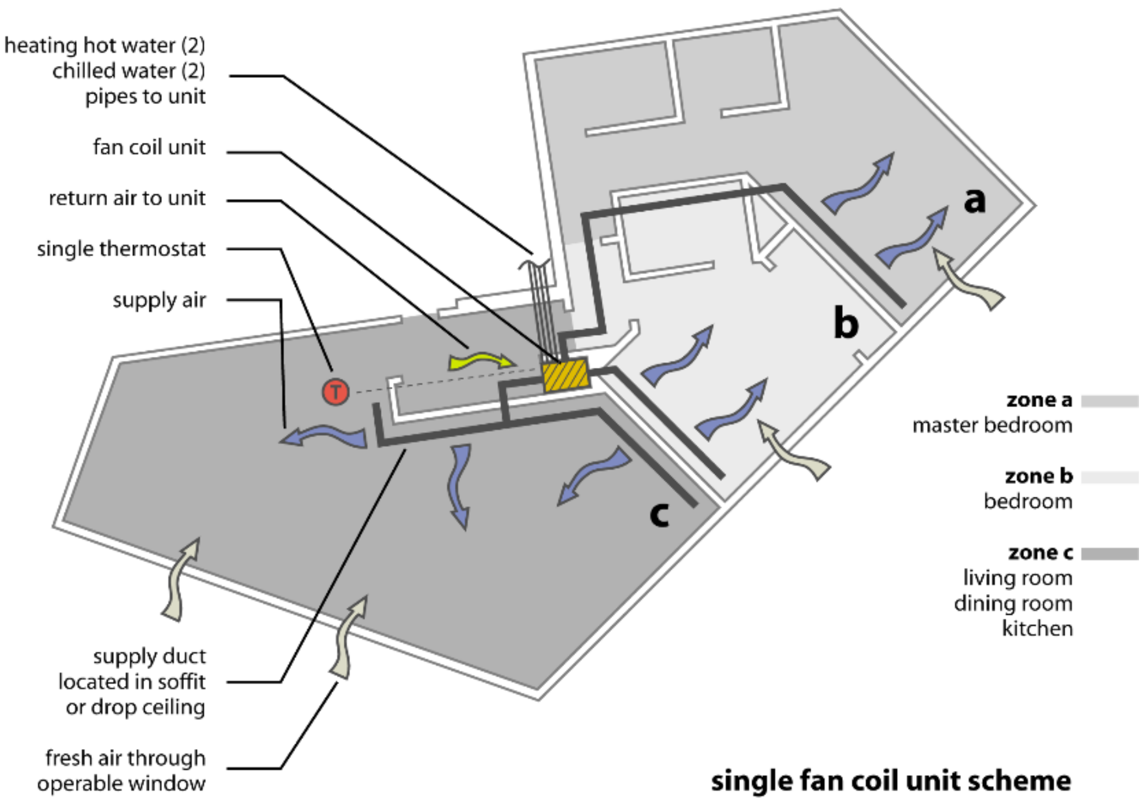

Figure 7. Typical fan coil conditioning system for a residential space.
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The utility company provide medium of high voltage power (typically 11kV to 66kV) to sub stations. Multiple sub stations are used to provide power from multiple sources within the building to provide redundancy. Utility power can be metered at sub stations with main switchgear usually placed in basement areas. It is normal to have multiple main switchgear which are isolated from each other and usually in different fire compartments.

Utility companies can have specific requirements for sub stations and switchgear. Sometimes there can be no specific requirements and sometimes there can be many specific requirements which are determined by the utility company, such as installing substations and switchgear against outside walls

Intelligent Building and Controls

When designing tall, supertall and Megatall buildings it is also essential to operate the buildings systems so the least amount of energy is consumed. The integration of smart building systems will increase the buildings efficiency and also provide more insight into the operation characteristics of the building. Maintenance of these large buildings can also be reduced by the introduction of automated fault detection and diagnostics in the building management system.

Smart building systems are building components that exhibit characteristics analogous to human intelligence. These characteristics include drawing conclusions from data or analyses of data rather than simply generating more data or plots of data, interpreting information or data to reach new conclusions, and making decisions and/or taking action autonomously without being explicitly instructed or programed to take the specific action. These capabilities are usually associated with software, but they can also be possessed by hardware with embedded software code or firmware. The line between systems that are smart and not smart is blurry, and for purposes of the chapter does not need to be absolutely defined. The purpose of this chapter is to introduce readers to emerging technologies that possess some of these "smart" characteristics.

These emerging smart technologies offer opportunities to reduce energy use and cost, while improving the performance of HVAC systems to provide better indoor environmental quality. Achieving these benefits requires knowledge of these emerging technologies. The chapter covers smart systems and technologies in the fields of automated fault detection and diagnostics, sensors and actuators, and the emerging modernized electric power grid and its relationship to buildings and facilities. ■

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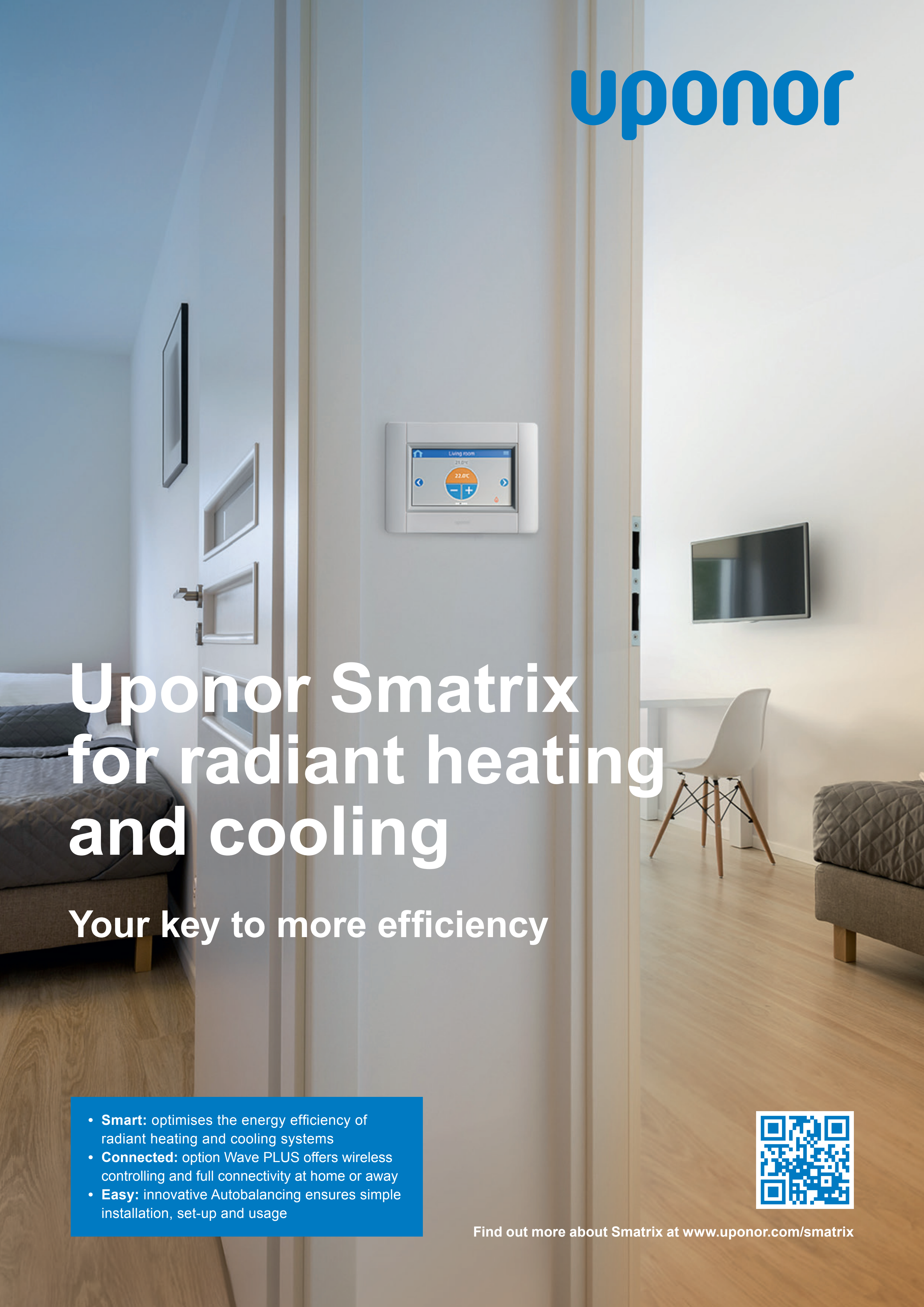
The ASHRAE Design Guide for Tall, Supertall, and Megatall Building Systems 2016 is currently available at the ASHRAE Bookstore www.ashrae.org.

About the author

Peter Simmonds has more than 35 years of experience in the design of HVAC systems for large and complex projects in the United States and overseas, including airports, museums, tall, super tall and megatall buildings, universities, hospitals and laboratories. Utilizing his own specially developed design and control techniques with designs representing the latest technology in improving thermal comfort, building performance and low energy usage, he has contributed innovative design solutions to many low and zero-energy efficiency projects.

Peter currently teaches at the University of Southern California, and is a lecturer for the Swegon Air Academy. In 2011 Peter was named an ASHRAE Distinguished Lecturer.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Lepenski Vir - the prehistoric energy efficient architecture

(The paper is an outline of the presentation at the Danube ASHRAE Chapter Meeting in Timisoara, Romania, 15th April 2016)

The prehistoric settlement of Lepenski Vir, which was discovered during the 1960s in Djerdap Gorge on the Serbian side of the Danube River, is well-known for its unusual architecture and preserved house floors. If we analyze this architecture in view of the set of natural (meteorological, geographical, astronomical and vegetal) environmental properties and consider energy consumption for heating and air-conditioning needs for such dwellings, i.e. achieving thermal comfort in those houses, we can conclude that the builders paid particular attention to energy efficiency in building stock while designing those houses. Remains of the architecture of the prehistoric settlement of Lepenski Vir, where operations for energy efficiency improvements are visible and recognizable, are the remains of an energy effective architecture. Their houses were energy efficient considering their age, technology and given location, contributing to the long life of the settlement.

Keywords: Lepenski Vir, energy efficiency, bioclimatic architecture, heat loads, solar energy, compactness.

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Introduction

The harmony of architectural style and natural environment has been taken into account since ancient times. In his presentation in Belgrade from two years ago, German engineer Helmut Krames asked the following question: "Did prehistoric people care about energy efficiency?" At this moment, we have to notice that people in the past were much better versed in the nature and its whims than we are nowadays.

Bioclimatic architecture is a new discipline in architecture, which nevertheless has a long tradition, and which relates to such issues. It should give an answer for questions with place of urban planning and structure designing in connection with elements of climate. The questions as follows:

1. Which is the optimum location and orientation for a building (if any choice is possible)?
2. Which are favourable and unfavourable climatic elements; how can they be adapted to the building in an optimum manner and vice versa?
3. How is it possible to improve the microclimate around and inside the building?

Those questions are in the book about bioclimatic architecture, written by Serbian architect Mila Pucar.

An architect needs to make sure that his or her design provides an answer to these issues by adapting the house to the climatic elements (like outside temperature, solar radiation, velocity and direction of wind, etc.) and surrounding vegetation (vegetation has a considerable impact on microclimate). Such a project results in comfortable indoor conditions and saving of energy from fossil fuels needed to achieve such conditions. The project needs to include implementation of RES (renewable energy sources). Solar energy could be RES applied in prehistory.

The basic information about archeological site Lepenski Vir

Lepenski Vir was discovered in the 1960s. The site is well known by its sculptures, architecture and graves. Lepenski Vir is settled on the right, Serbian side of the Danube River in Djerdap Gorge, 15 km upstream from Donji Milanovac and about 160 km downstream from Belgrade.

The person deserving most merit for its discovery was Dragoslav Srejović, archeologist, whose book *Lepenski Vir – a new prehistoric culture in the Danube region,* published in 1969 by SKZ, is the main source of information on this culture. The site is estimated to be about 8,000 years old. Due to construction of HEP Djerdap 1 the original site was sunken, the level of the Danube grew by about 12 m, while the current site was moved by some 150 m, but the original position was maintained.

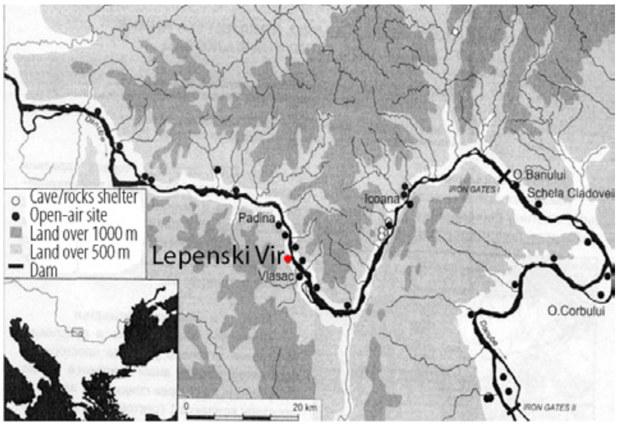

Figure 1. Places of Lepenski Vir culture. [3]

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The recent bloom of solar architecture took place after the excavations, in mid-1970s, following the beginning of the energy crises and so-called "petrol shock". This is why the passive solar heating aspect was not taken into consideration during the excavations in Lepenski Vir.

Nowadays, Lepenski Vir is a museum. The site was displaced due to sinking. The museum preserves the site from devastation due to climatic effects.

Only bases of the houses, made from a hardened material resembling concrete, are preserved; hearths were incorporated in the bases at the entrance, as an active heating system. The third dimension was constructed from perishable materials (like wood, leather, mud…) and is not preserved. We can only assume what those houses looked like. The architecture is characterized by houses with the base shaped like a truncated section of a circle, with the convex side turned to the river, i.e. sunrise. This shape may also be called a convex trapeze (see **Figure 2**).

The back side is significantly smaller, while the front side is shaped as a circular arch. Lateral sides are inclined. The hearth made of stone blocks in the bank-hinterland direction was placed at the entrance of the house (see **Figure 3**). At the first look we can see that

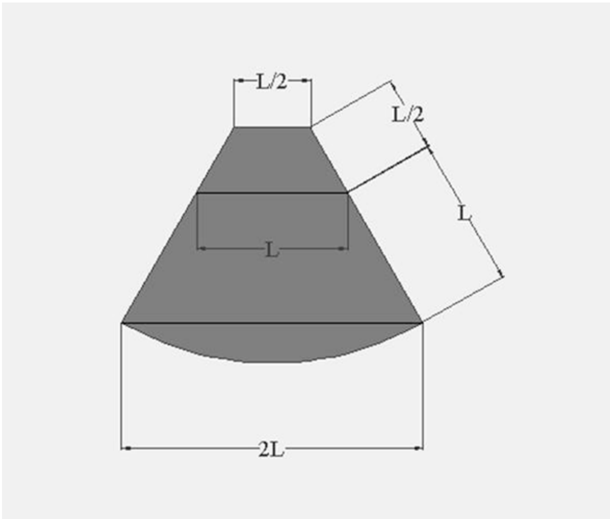

Figure 2. The shape of the base by Dragoslav Srejović. [19] *Please check this image in better resolution on the REHVA Journal digital version.*

Figure 3. Photo of the base. [1]

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hearth at the entrance was placed from the same reason why we install radiator under the window today.

Many, including Srejović himself, wondered: How did this house look in space? Almost nobody asked: What was the point of such construction and why were these houses built in this manner? The answer to the second question may be found even without an accurate answer to the first one. The purpose is obvious: to achieve pleasant living conditions within natural surroundings. The reconstruction of the house was given also by Pedja Ristić, Hristivoje Pavlović, Dušan Borić and others.

Visible energy efficiency principles in the architecture of Lepenski Vir

Winter time – reduction of conduction and ventilation heat loads

What principles were applied in the architecture of Lepenski Vir for reduction of conduction heat loads?

The first principle for reduction of conduction heat loads is compactness. A/V ratio is important as a measure of compactness. If a building envelope is compact, A is smaller and conduction heat loads are smaller. The best figure in that case is the ball.

At Lepenski Vir we know only the floors, so we should consider the perimeter and surface ratio, and then make an analogy to the third dimension. The best figure in two dimensions is a circle.

If we observe shape comparison figures in **Table 1**, we can see that the cylinder with optimized floor at Lepenski Vir is somewhere in the middle. The shape of many houses and buildings have today much less favourable A/V ratio than a cube.

Table 1. Shape comparison.

Figure	A/V for V=1	%	%, If we calculate orientation
Ball	4.84	80.6	80.6
Cylinder	5.54	92.26	92.26
Cylinder – optimized Lepenski Vir floor – south orientation	5.68	94.68	93.94
Cylinder – optimized Lepenski Vir floor – east orientation	5.68	94.68	94.68
Hemisphere	5.76	95.96	95.96
Cube	6	100	100

Floors at Lepenski Vir were very compact. The floor is a combination of a trapeze and circular section. The perimeter of this or similar figure is smaller than of a square. Heat transfer and losses are smaller with this shape. If we compare a cylinder with optimized basis of Lepenski Vir floor with a cube, it saves 5–7% energy in conduction heat loads (if we calculate orientation too). This shape at Lepenski Vir has a good quality in passive solar architecture.

The second principle for reduction of conduction heat loads applied at Lepenski Vir is orientation. Advantages of this asymmetrical or eccentric shape are manifested if adequate orientation is applied. Orientation at Lepenski Vir is mostly to the east and to the river. Southward orientation at the given site was not favourable. Due to ground configuration and hills in hinterland, the construction site was mostly exposed to solar radiation in the morning; the site was facing the river.

The third principle for reduction of conduction heat loads is usage of solar energy for better thermal insulation. Materials applied for construction of the envelope were from the natural local setting. Materials applied for "walls" were mostly wood, leather, mud… All these materials lose their thermal insulation properties under the impact of moisture. Precipitation in Djerdap is by 20% larger than in adjacent areas. Drying of inclined walls in the sun improves thermal characteristic and increases insulation rate. Thus, conduction losses are diminished.

Conduction losses were reduced by compact envelope, drying of walls and improvement of thermal insulation properties of materials used for walls by application of solar radiation, which is why favourable orientation was used.

For reduction of ventilation heat loads, two principles work together: aerodynamic shape and proper orientation. It may be assumed that the settlement was exposed to winds blowing from the river, as the vegetation and steep hinterland reduce the possibility of wind blowing from other directions. The shape of the base is also very favourable from the perspective of loses in ventilation, as it allows for natural circulation with small drops and differences in pressure, enabling maintenance of favourable indoor temperature. The aerodynamic shape of the base, which is much better than, e.g., a square, i.e. cube, is exceptional.

Aerodynamic shapes reduce infiltration of external air into the structure interior. Thus, movement of air indoors is minimized, and heat exchange with surroundings is reduced. The disposition of air vents (windows) is not familiar, which is why calculation of heat losses is pointless. Ventilation losses, which were pronounced, were reduced by using the base of the favourable aerodynamic shape with proper orientation. Wind gusts were reduced by front arc side.

The third principle for reduction of ventilation heat loads is digging walls with earth. It is known that soil has better thermal properties than ambient air. Digging is also implemented for the purpose of protection from wind. The back side of the house was dug due to ground configuration and for protection from wind. The height of digging was between 80 cm and 1 m. In some places, such structure also acted as the retaining wall. The settlement was terraced. Ventilation losses were minimized by the favourable aerodynamic shape, orientation, and digging.

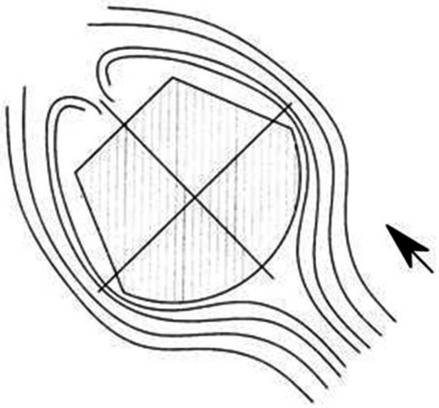

Figure 4. Circulation – the aerodynamic shape of optimized floor at Lepenski Vir.

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Summer needs for cooling

Such architecture may also provide comfortable living conditions in summer. Microclimatic benefits are utilized by the choice of site. Steep hinterland on the west casts shadow on the settlement in the afternoon. This reduced summer heat gains. Thermal load is the largest in the afternoon because of joint action of high outside temperature and solar radiation.

Selection of the location, with all its microclimatic benefits, was very important (in Djerdap, in July it is by 2–3°C colder, while in January it is by about 1°C warmer than in adjacent regions). The need for cooling in summer was reduced by the choice of a favourable location and orientation and utilization of vegetal surroundings. Additional cooling was achieved with simple technic – splashing walls and a floor with river water to evaporate and lowers the temperature.

Figure 5. The terraced settlement and digging.

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The choice of the location, steep hinterland, orientation and vegetal surroundings also enable pleasant living conditions in summer.

Some others secondary energy efficiency principles

In Lepenski Vir, minimization of conduction and ventilation losses in winter and reduction of heat load in summer were achieved using the same beneficial orientation: this **beneficial orientation was towards the east and the river**, resulting from ground configuration.

Energy "production" (heat and light gains from solar radiation) and energy demand (walls mostly need to be dried in the morning after dew) are well-aligned, which is reflected in the choice of orientation. Morning temperatures are lower than outside temperatures in daytime, which is why the need for heating is the greatest in the morning. Outside daily temperatures are the lowest before sunrise. This alignment is mostly due to the predominantly eastward orientation of houses, towards the river.

The Padina-Gospodjin Vir site

Excavations were also performed at the Padina-Gospodjin Vir site, overshadowed by the discovery at Lepenski Vir. Padina-Gospodjin Vir is also a sunken archaeological site, located some 6 km upstream from Lepenski Vir. It was located on the western, Serbian side of Djerdap; the natural conditions were quite similar to those at Lepenski Vir. The found remains of architecture are very similar to the architecture of Lepenski Vir, but also differ from it in some details.

Excavations were performed by academician Borislav Jovanović before the site was sunk. The architecture of the Lepenski Vir culture did not emerge haphazardly, as similar house remains were found both in Lepenski Vir and in Padina-Gospodjin Vir, sunk archaeological site in the vicinity, with similar microclimatic conditions.

Figure 6. Side view of steep hinterland.
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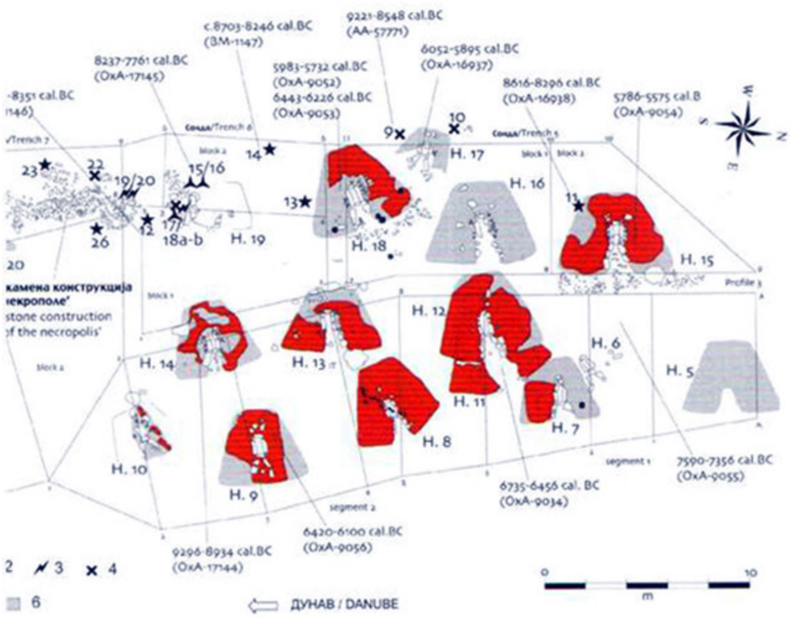

Figure 7. The layout of the base of Padina-Gospodjin Vir settlement. [5]
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Conclusion

We may speak about the primal passive solar and bioclimatic architecture. The shape of houses is very compact and contributes to saving of heating or cooling energy. The remains of the architecture of Lepenski Vir are silent witnesses of measures applied to improve energy efficiency. The houses in Lepenski Vir and Padina-Gospodjin Vir are examples of energy efficient construction of the time, location and given the condition of technology and applied materials. The architecture of Lepenski Vir did not emerge haphazardly, as similar house remains were also found at the Padina-Gospodjin Vir site.

The inhabitants of Lepenski Vir and Padina-Gospodjin Vir were aware of some principles of bioclimatic architecture. This is proved by the remains of architecture (house floors) and natural surroundings of the site, including movement of the Sun along the firmament. This is also proved by the fact that in this settlement and at that site people were living for about 2,000 years, or about 80 generations* (let us remember the definition of sustainable development!).

The answer to the question of Helmut Krames, engineer, from the beginning of the paper, whether people in prehistory cared about EE in building stock is: the remains of the architecture of Lepenski Vir (including the Padina-Gospodjin Vir site), which emerged some 8,000 years ago, indicate to recognizable measures aimed at increasing EE in building stock, which were implemented in the design and construction of houses and settlements at those sites. Even though there is no written evidence, bases of the houses speak about the applied measures the sense of which may be grasped only when observed within the natural (geographic, meteorological, vegetal, and astronomic) surroundings. The role of the Sun and solar radiation on the sites is very important to understand the purpose of the architecture of Lepenski Vir. Even though we may not be certain of what those houses looked like, we may positively conclude, based on the remains of the architecture, that the purpose of such construction was to ensure comfortable conditions in them, taking into consideration energy efficiency in buildings. Even though the third dimension of the house is not known, it must have followed the shape of the preserved base. **The remains of architecture in Lepenski Vir are the remains of an energy efficient architecture and ecological houses.** ■

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* The data from this paper relating to the 2,000 years, or about 80 generations of duration of the settlement, needs to be taken only as a rough illustration of the long life of the settlement.

Controlling urban runoff

TEXT AND PHOTO: MINNA KÄRKKÄINEN
Pictures: VTT / Erika Holt

With new inventions and smart urban planning, new urban areas handle heavy rainfall better and better. Also old and densely built cities will benefit from new solutions to managing storm water problems.

A beautiful summer day can turn into a rainstorm, pouring down dozens of millimeters of rain in one night. Soon streets are suitable only for canoeing. Cars are stuck in flooded underpasses. Sewers are blocked, buildings and citizens in danger.

This kind of heavy rain is luckily quite uncommon – for now. Extreme weather conditions are expected to increase in the future.

“Great variation in the amount of rainfall is a huge issue for cities. Winds and horizontal rain are also increasing”, says research professor **Miimu Airaksinen** from VTT technical research center of Finland.

Controlling storm water runoff is an important issue for a functional city. Solutions for future cities have been researched at the VTT in the international Smart City -project led by Miimu Airaksinen.

In co-operation with the Finnish Meteorological Institute, the VTT has developed a simulation which can generate a 3D city model with elevations, networks and surface penetration. With this model, it is possible to investigate, where water will start to pool, where it can penetrate structures and which are the high-risk areas. This model will also show if a crucial building is in the danger zone.

“This is crucial information for property owners, cities and insurance companies alike, as it is one of insurance risk factors. Being aware of the risks isn’t enough though, we have to have solutions for them. We have studied how we can prepare better for heavy rainfall. For example, special coatings can be installed and we can develop temporary rainwater harvesting systems”, Airaksinen lists.

VTT research professor Miimu Airaksinen and her team are solving big questions about urban planning: how to effectively create a functional and sustainable city.

According to Airaksinen, the infrastructure in Finland, such as houses, water and sewage systems as well as roads, have huge potential for improvement. It is important that the needs for improvement are found well in advance and plans how to improve the quality of the system in the future are done at the same time. This way the price tag for improvements stays reasonable.

Smart technology, such as sensors in sewage systems, will also remove the need for unnecessary and premature repairs. With accurate real-time data, maintenance funds can be invested where they are needed the most.

“New technology can create surprising flexibility and can help break away from traditional thinking patterns.”

City planning

"Nature based solutions are a widely discussed topic at the moment: for example, how recreational areas can also be used as buffering for storm waters", Airaksinen explains.

In new developments, introducing novel solutions is naturally much easier compared to old urban structures. In new areas under construction at the moment, the managing of storm waters has been planned particularly well. City planners are well up to date with the latest developments.

"The city rarely dictates one certain way to deal with storm water management. Usually all that needs to be done is to prove the functionality of the solution, because it is always possible for someone else to come up with a more brilliant idea."

There are many ways to prepare for rainfall. Airaksinen says that usually the cheapest way to control rain waters is permeable paving. A backup plan is always incorporated into the design of the sewage system. In case a system fails, it has already been thought out, how another system will carry out its function.

This kind of planning creates other benefits as well. For example, building wetlands or lakes to incorporate rainwater makes the area more attractive, and cost-efficiency is improved as the amount of water conveyed to the sewage systems is reduced.

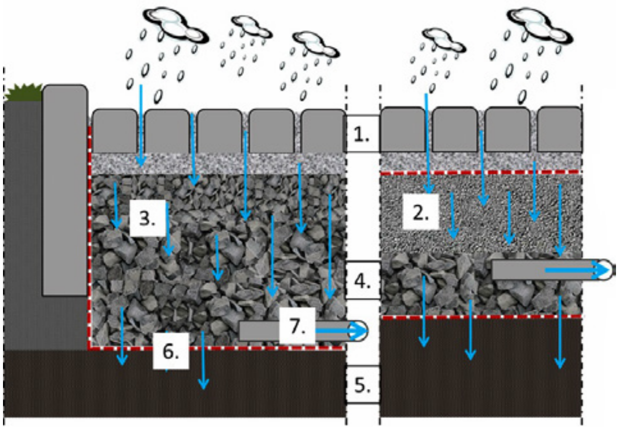
Airaksinen mentions Vuores suburb in the city of Tampere as an interesting new area regarding rain water control. There professionals have planned how the existing sewage system can cope with the expansion of the development. While planning the placement of houses, the function of green areas as buffer zones is taken into consideration. The utilization of green roofs has also been considered.

Below the surface and under the sky

Asphalt is a pleasant surface to walk and drive on, but is impervious to water. New pavement materials are pleasantly smooth, but can also be permeable to even large amounts of water. Permeability has been researched in the VTT laboratory and Airaksinen says result are very promising.

In future city pavements, the gaps in brick paving are well optimized. Streets have to be comfortable

In Vuores suburb in Tampere, controlling rain water is thoroughly planned. This park is a recreational area, but it will also help in controlling rain waters.



1. Pervious interlocking concrete pavement
2. Pervious concrete (base)
3. Porous aggregate base
4. Porous aggregate subbase for water retention
5. Subgrade
6. Geotextile
7. Underdrainage and piping when needed

Examples on climate-adaptive surfaces, i.e. pervious pavements. Surface layer is designed to have high water permeability, and base and subbase structures are with high porosity and permeability, and are designed for water detention. Picture: Erika Holt.

Hydrological simulation of water pervious structures and pavements. Water infiltration capacity, retention capacity, and if needed also water purification capacity, is simulated in a full-scale (adjustable: 330 -1000 mm) rig, with continuous measurement of the amounts of water: sprinkler irrigation and water passed through the structure. Photo: Erika Holt.

Please check this image in better resolution on the REHVA Journal digital version.

for walking and driving, and work well under winter conditions. Simultaneously, the material between bricks works effectively allowing water penetration.

If not in a groundwater area, rain waters can be left to freely absorb to the ground. The water can be removed also after the permeating layer, if need be. Furthermore, roofing materials are now researched, as in urban areas roofs constitute a large percentage of the overall surface area.

Green roofs are very common in Europe and are making their way to Finland as well. But similar to other construction, building green roofs requires more effort in the northern altitudes. Plants that are selected to green roofs must tolerate the heat of the summer days, but also the snow and freezing temperatures of winter.

Airaksinen also points out that a green roof cannot be added to any building, particularly of the existing housing stock. But a well-functioning green roof can offer a refreshing recreational area, which increases the value of the real estate. In hot weather, the green roof has a cooling effect on the microclimate of the building.

Smart City

Smart city offers an ideal living environment. Everyday life runs smoothly and pollution prevention is cost-effective. In the VTT, this is considered one of the key points of focus.

The team of 50 experts that makes up Smart City consists of energy, construction, transport, power and ICT specialists and behavioral scientists.

"Smart technology is created to make everyday life easier, not because it is fun to have as many technological gadgets as possible", says the project leader, research professor Miimu Airaksinen.

One of Smart City's focus areas is energy systems.

"For example, we research how the energy systems of a city should change. We're looking for the optimum level of how much to improve a building's energy efficiency and how to get full benefit of the systems."

Smart City researchers have noticed that even small adjustments can bring great savings at the regional level, which is noticeable in energy production as well. Furthermore, emissions are reduced.

"We have developed self-learning algorithms for predicting the residents' needs in the building. This way we can optimize conditions and energy use. We always prioritize optimal conditions", Airaksinen emphasizes. CITYkeys Smart City performance measurement – project is carried out in cooperation with Tampere and four other European cities. The network consists of 20 other European cities and the number is growing. Results will be published at the end of the year.

Detailed information

Highly developed technology, such as remote sensors, can predict extreme situations and help in controlling storm water.
"When sensor technology and wireless data transfer develop further, we are more prepared, for example, to call for assistance."

In the future, the need for extra pumping systems in different parts of the city can be predicted even before there is water on the streets.

"This is a big leap in development. Rain can cause severe structural damage, but also create acute security risks. For example, if fire trucks or ambulances are prevented from getting to those in need of help", Airaksinen describes.

It is very typical in cities, that rainwater and sewage waste are transported through the same pipes. Therefore, controlling rainwater is critical, because flooding also creates a hygiene risk. Who would want to wade in faeces?

Finnish cities are spacious compared to many other European cities. European metropolises have mostly stone paved streets, which have very little permeable surfaces and floods are a common problem.

Highly innovative industry is also an advantage in Finland. According to Airaksinen, many sensor and automation manufacturers and companies specialized in pavement technology welcome opportunities of product development in research cooperation with the VTT. An example of cooperation is the CLASS-project lead by the VTT (www.vtt.fi/sites/class).

"Know-how is needed from both industries: pavements and sensing technology. Developing new solutions has been easy together with the industry, as new innovations have been incorporated into practice immediately. In many countries this is not so easy."

Certainly development is also fast elsewhere. In Southern Europe the possibilities of collecting and storing rainwater for relieving subsequent droughts is under investigation. ■

ISO 18566, the international standard on the design, test methods and control of hydronic radiant heating and cooling panel systems

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This article introduces the structure and contents of under developing 'ISO 18566 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems.' This is the second international standard on radiant heating and cooling system. ISO 18566 includes: technical specifications and requirements of radiant heating and cooling panel system, the test facility and test method for heating and cooling capacity of ceiling mounted radiant panels and the design considerations and process of ceiling mounted radiant panels, and the control of ceiling mounted radiant heating and cooling panels.

Application field of the ISO 18566

Typical applications are low temperature radiant heating and high temperature radiant cooling and are classified as embedded radiant heating and cooling system and prefabricated radiant heating and cooling panel system. ISO 11855 standards are for embedded radiant heating and cooling system without open air gap. The developing ISO 18566 standards are for radiant heating and cooling panel system with open air gap. This standard specifies the design, test conditions and methods for the determination of the heating and cooling capacity and control of radiant heating and cooling panels with an open air gap. This standard applies to all types of prefabricated radiant panels that are part of the room periphery such as ceiling, walls and floor. This standard does not cover panels embedded into ceiling, wall or floor structures and hybrid (combined thermal radiation and forced-convection) ceiling panels.

And the experts agreed that this work item would be based on existing standards such as EN 14240, EN 14037 and ANSI/ASHRAE Standard 138 and experts in ISO/TC205/WG8 decided to develop a new ISO 18566 series. In the beginning, this standard was suggested to have 6 parts:

- Part 1: Definition, symbols, technical specifications and requirements
- Part 2: Design of ceiling mounted radiant panels
- Part 3: Test facility for thermal output of ceiling mounted radiant heating and cooling panels
- Part 4: Test method for cooling capacity of ceiling mounted radiant panels
- Part 5: Test method for heating capacity of ceiling mounted radiant panels
- Part 6: Control and operation of ceiling mounted radiant heating and cooling panels

This new proposal was approved in January 2013. The proposed new standard will affect the manufacturers of radiant heating and cooling panels and also mechanical engineering companies. They can use the proposed ISO standards for determining the thermal output of radiant heating and cooling panels and for designing the HVAC system.

Ceiling mounted radiant heating and cooling panel systems have become more popular for new building construction as well as renovation projects in Europe, USA and Asia because they can provide a comfortable environment by controlling surface temperatures and minimizing excessive air motion within the space. As shown in **Table 1**, there are several existing standards regarding ceiling mounted radiant panels in Europe and USA. However, there is no single and comprehensive international standard for the design of ceiling mounted radiant heating and cooling panel systems. This ISO 18566 standard covers this lack of standardization by addressing the technical specifications and requirements, the determination of test method for thermal output, design considerations and control methods all together in one standard.

As shown in **Table 1**, CEN had been working on developing related standards to describe the test method for thermal output and rating method of ceiling mounted radiant panels during heating and cooling operation and finally developed EN 14240:2004 and EN 14037 in May 2003 (see **Table 1**). Part 1 of EN 14037 defines the technical specifications and requirements of ceiling mounted radiant panels, heating and cooling surfaces fed with water at temperatures below 120°C connected with a centralized heating and/or cooling supply source. And this also defines the additional common data that the manufacturer shall provide to the trade in order to ensure the correct application of the products. But this does not apply to independent heating and/or cooling devices. Part 2 of EN 14037 describes the test method and the test facility for determining the thermal output of ceiling mounted radiant panels according to the specifications of EN 14037-1. And part 3 of EN 14037 describes the procedure to determine the rated thermal output (Φ_D) and the mean surface temperature (t_{rp}). This test method for determining the thermal output of ceiling mounted radiant panels give reliable results for comparing different products. Meanwhile this EN 14037 series has been revised in September 2015.

Table 1. Relevant standards regarding ceiling mounted radiant panels.

Reference Standard	Title	Publication Date
EN 14037-1	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 1: Technical specifications and requirements	01 May 2003
EN 14037-2	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 2: Test method for thermal output	01 May 2003
EN 14037-3	Ceiling mounted radiant panels supplied with water at temperature below 120°C – Part 3: Rating method and evaluation of radiant thermal output	01 May 2003
EN 14240	Ventilation for buildings. Chilled ceilings. Testing and rating	29 Jan. 2004
ANSI/ASHRAE Standard 138	Method of Testing for Rating Ceiling Panels for Sensible Heating and Cooling	28 Jan. 2009

Design, test methods, control and operation of radiant heating and cooling panel systems.

- Part 1: Definition, symbols, technical specifications and requirements
- Part 2: Design of ceiling mounted radiant panels
- Part 3: Test facility for thermal output of ceiling mounted radiant heating and cooling panels
- Part 4: Test method for cooling capacity of ceiling mounted radiant panels
- Part 5: Test method for heating capacity of ceiling mounted radiant panels
- Part 6: Control and operation of ceiling mounted radiant heating and cooling panels

ISO 18566 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems

- Part 1: Definition, symbols, technical specifications and requirements
- Part 2: Determination of heating and cooling capacity of ceiling mounted radiant panels
- Part 3: Design of ceiling mounted radiant panels
- Part 4: Control of ceiling mounted radiant heating and cooling panels

Figure 1. Development of ISO 18566 series structure.

EN 14240 specifies test conditions and methods for the determination of the cooling capacity of chilled ceilings and other extended chilled surfaces. This test method applies to all types of surface cooling systems using any medium as energy transport medium. This standard refers to water as the cooling medium throughout. In addition, this standard refers to chilled surfaces which include ceiling, wall or floor as appropriate.

At the development stage, these standards were assigned to ISO/TC205/WG8. Finally, the ISO 18566 series consists of 4 parts and deals with, free hanging hydronic radiant heating and cooling panel systems. This standard specifies the design, test conditions and methods for the determination of the cooling and heating capacity and control of radiant heating and cooling panels with an open air gap. This standard applies to all types of prefabricated radiant panels that are part of the room periphery such as ceiling, walls and floor.

ISO 18566-1specifies the comfort criteria, technical specifications and requirements which should be considered in manufacturing and installation of radiant heating and cooling systems. Part 2 provides the test facility and test method for heating and cooling capacity from ceiling mounted radiant panels. Part 3 specifies the design considerations and design processes of ceiling mounted radiant panels. And part 4 addresses the control of ceiling mounted radiant heating and cooling panels to ensure the maximum performance which was intended in the design stage when the system is actually being operated in a building.

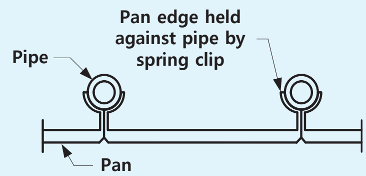
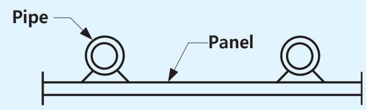
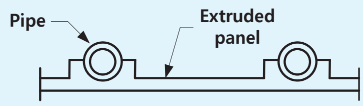
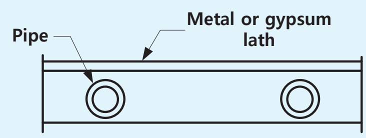
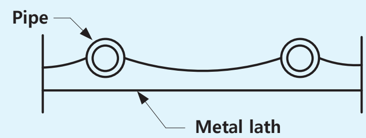
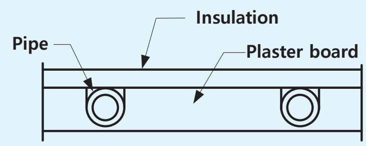
Technical specifications and requirements in part 1

Technical specifications include the system types, specifications which are to be considered in manufacturing and installation stage. The technical requirements include the thermal and hydronic performances, safety and maintenance.

Major types of radiant panels

The radiant panel system is characterized by open air gap. The major components of radiant panel system are a radiant panel and pipes. The types of radiant panels were generally determined by the arrangement of major components. For each type, the heat transfer characteristics are different. Insulation is necessary for preventing heat losses to unoccupied part of the space. In addition, a heat transfer layer, fixing equipment (hangers, wire net, and etc.) and finishing material (plaster and etc.) may be necessary. The major types of a radiant panel are illustrated in **Table 2**.

Table 2. Major types of a radiant panel.

Description	Shape
Pipes fixed to pan edge	
Pipes secured to panel	
Pipes fixed to extruded panel	
Pipe fixed under metal/gypsum lath	
Pipe fixed on metal lath	
Plaster board	

Specification

The thermal output of a radiant panel is mainly transferred to the space by radiation. The thermal output on the reverse side of the panel to the unoccupied part of the space shall be minimized by insulation. So the non-heated or non-cooled side of the radiant panels shall be provided with insulation. The thermal resistance of the insulation has a substantial influence on the thermal output to unoccupied space. The surface of the radiant panels require protection against corrosion. For example, the paint used for protection shall not contain any chemical substances which is not allowed in building products. And the compliance with the relevant domestic regulations shall be stated by the manufacturer of the radiant panel. The radiating heating/cooling surface shall have an emissivity not lower than 0,8. The dimensions of plastic pipes must comply with the requirements of the following ISO 15875-1 for PE-X, ISO 15876-1 for PB, and ISO 15874-1 for PP. Copper piping must comply with the requirements of EN 1057 (for pipes) and EN 1254 (for fittings). Minimal pipe thickness should comply with the requirements for service conditions, operation pressure (higher than 4 bar) and durability (more than 50 years). The use of pipes with an oxygen-barrier layer is recommended to reduce corrosion problems. The oxygen permeability should be less than or equal to ($0{,}1\ g/m^3 \cdot d$) at a water temperature of 40°C, where d is the average outer diameter of the pipe.

During the installation of the panel system, it is necessary to ensure that the fixing point can bear the load of panels and ensure that the coupling should be installed to prevent leakage. The fixing points on the radiant panel shall be designed to withstand a load of 5 times the allocated mass of the panel, including water, without failure. A loading up to 3 times of the allocated filled mass shall be achieved without any occurrence of permanent deformation. The manufacturer shall submit a statement for the suitability and stability of the fixing points in accordance with national regulations if exist, rather than recommended values. When coupling a panel to other panels, the bending radius shall not be less than the minimum bending radius defined in the relevant product standards. This operation should be carried out in accordance with the manufacturer's instructions.

Technical performance

The rated thermal output and the thermal output under different operating conditions (characteristic curve) are to be determined in a test laboratory according to the part 2 of this standard. Thermal performance is influenced by insulation which prevents thermal output to unoccupied space. The manufacturers shall declare the rated thermal output of the radiant panels. And the manufacturer shall provide the means to calculate water flow resistance for the different types of unit with connections and internal pipe layout.

The water flow distribution for the panels should be balanced. When no manifold is applied, the distribution method by piping like reverse return should be used. When manifold is applied, headers, flow control valves, actuators and air discharge valves should be used. The installation specification should be carried out in accordance with the manufacturer's instructions. The water flow within a pipe is necessary to be turbulent (Re>4000) to enhance the thermal performance. However, laminar flow may be acceptable in some cases (e.g. at low load situation). Laminar flow is also considered in part 2 and 3 of this standard. The lower end of velocity range is based on the ability of flowing water to move air bubbles along a vertical pipe. The average flow velocity of 0,6 m/s or higher can entrain air bubbles that are in a downward water flow. The upper end of velocity range is 1,2 m/s which is based on minimizing noise generated by the flow.

Safety

The headers and their connections to the pipes of the active length (wet surface) of all products leaving the factory shall be tested for leaks with a test pressure equal to at least 1,3 times the maximum operating pressure stated by the manufacturer. The materials from which the appliances are made (steel, aluminium, plaster board, etc.) should be considered to meet required fire class. In EU countries, the appliances made from steel or aluminium are considered to be reaction to fire class A1 without the need for testing (provided that any organic part of the paint or coating is less than 1% by mass or volume). If the organic part of the paint or coating exceeds 1% by mass or volume, the material shall be tested and classified according to EN 13501-1 and the resulting class stated.

Determination of heating and cooling capacity of ceiling mounted radiant panels

ISO 18566-2 deals with the determination of heating and cooling capacity of ceiling mounted radiant panels. Ceiling mounted radiant panels covered by this standard are limited to a width from 0.3 m up to 1,5 m. This standard also defines the additional common data that the manufacturer shall provide in order to ensure the correct application of the products.

Test booth

The booth for testing ceiling mounted radiant panels shall be constructed in a way that all six surrounding surfaces can be chilled. Walls, ceiling and floor shall have smooth inside surfaces covered with a coat of mat paint having a degree of emissivity of minimum 0,9. The test booth construction shall be sufficiently tight to prevent air infiltration.

During the heating capacity test, the cooling system will be operated to maintain the temperature difference between the 6 surrounding inside surfaces of the test booth is not higher than 0,5 K. That condition shall be maintained at the tests for the determination of the characteristic equation.

During the cooling capacity test, the test booth will be heated with a number of electrically heated cooling load simulators which are positioned on the floor of the test booth for covering the cooling capacity. The output of each simulator must not exceed 180 W and shall be continuously adjustable. Each simulator shall have an identical heat output. The housing of the simulator is made of painted steel sheet. The emissivity of the inside and outside surface shall be at least 0,9. The active power of the simulators shall be measured with a measuring instrument of the accuracy of 1,0% or better. The surfaces, floor and ceiling of the test booth shall be insulated in the way that the average heat flow in those surfaces is lower than 0,40 W/m² during the test. This heat flow shall be determined by preliminary calibration tests of the booth or by calculations. The reference temperature during the measurement shall be 32°C ± 0,5 K in the steady condition for minimum 30 minutes. The temperature(s) of inner surfaces of walls, floor and ceiling of the test booth (under the insulation) shall be controlled and be kept at the value, which is necessary to guarantee a maximum temperature difference between these surfaces and the reference temperature be less than 1,0 K.

Test method

The aim of the thermal output test is to establish the standard characteristic equation of a ceiling mounted radiant panel by determining the related values of thermal output and cooling capacity and temperature difference. Neither of these quantities can be measured directly, but shall be calculated using the values of other measurable quantities, either directly or with additional information (calibration test, material properties table), by using mathematical relationships.

The thermal output Φ_{me} is calculated based on the water flow rate q_m and the measured temperatures q_1 and q_2. These temperatures are used to calculate the specific enthalpies (h_1 and h_2) as determined by the international steam tables at a reference water pressure of 120 kPa:

$$\Phi_{me} = q_m(h_1 - h_2) \qquad (1)$$

The water flow rate is measured directly by a calibrated flow-meter in a closed water circuit or calculated using the mass of the water m collected in a measuring vessel and the relevant time interval τ. The standard provides detailed requirements for the position of the panels in the test booth, the water flow rate, temperatures, installed insulation at the panel and the connectors.

Test Report

The following data shall be stated in the test report:

- Name and address of the test institute
- Location of test (if different from the test institute)
- Name and address of the customer
- Identification of the test method used
- Description of the test booth
- Identification of the test samples including trade mark, model number and dimensions
- Dates of testing
- Documents of the manufacturer (drawing No, report of the pressure test, report of the factory test) confirmation of the producer or declaration of product identity
- Test results:
  - Results of the resistance to pressure test
  - Control of the general construction specifications
  - Control of the dimensional tolerances, all dimensions of the test sample shall be documented with the nominal dimension, the measured dimension, nominal tolerance and the measured differences in a table.
  - Test data including e.g. water temperatures, air temperatures, globe temperature, water flow rate, corresponding Reynolds number at 50°C (heating case)
  - Standard total output and the characteristic equation of the tested panel
  - Standard output and the characteristic equation of the active length of the tested panel
  - Standard output and the characteristic equation of connection components of the tested panel
  - Standard modular output and exponents of the tested panel and the interpolated/calculated panels
  - Rated thermal output of the tested panel and the interpolated/calculated panels
  - For characteristic equation with deviations from the standard characteristic equation
    - Exact description of the boundary condition: parameters, thermal output values of standard temperature difference, equation for the characteristic.

Design of ceiling mounted radiant panels

The ceiling mounted radiant panels work by circulating warm or cold water through pipe circuits. Radiant heating and cooling panels can be installed in a single room or throughout an entire building, and it is used for areas with normal and high ceilings. Ceiling mounted radiant panels function as heat exchangers between the room air and the chilled/hot water. The ceiling panels absorbs or emits heat from heat sources in a room and exchanges it with the circulating chilled/hot water. After the heat emission from panel surface, the chilled or hot water is transferred to a chiller or boiler. With radiant panel systems, room thermal conditions are maintained primarily by direct transfer of radiant energy rather than by convection heating and cooling. Radiation heat exchange takes place between objects with different surface temperatures. In order to provide acceptable thermal conditions, air temperature and mean radiant temperature should be taken into account. Compared with conventional convective heating and cooling systems, a radiant heating system can achieve the same level of operative temperature at a lower air temperature and a radiant cooling system at a higher air temperature. However, in all practical thermal environments, a radiation field has an asymmetric feature to some degree. If the asymmetry is sufficiently large, it can cause discomfort. Also the thermal stratification of air may cause thermal discomfort. Therefore, these comfort criteria should be considered at the design stage of ceiling mounted radiant panels. Furthermore, ceiling mounted radiant panels are generally built as an architectural finishing product. And generally the copper pipes are thermally bonded and panel piping arrangements are in a serpentine pattern or in a parallel pattern. So ISO 18566-3 specifies the design considerations such as thermal resistance in the panel, panel heat loss or gain, water velocity in pipes and surface condensation problems during cooling operation. Also this addresses the basic design process, including key points to consider while designing a ceiling mounted radiant panel system.

General design consideration

Thermal resistance in the panel to transfer heat from or to its surface will reduce the thermal performance of the panel itself. Thermal resistance to the heat flow may vary considerably among different panels, depending on the type of bond between the piping and the panel material. Influential factors such as corrosion or adhesion defects between lightly touching surfaces and the method of maintaining contact may change the bond with time. The actual thermal resistance of any proposed system should be verified by testing. And specific resistance and performance data, when available, should be obtained from the manufacturer.

Heat transferred from the upper surface of ceiling panels is considered as a panel heat loss. Panel heat losses are part of the building heat loss if the available heat is transferred outside of the building. If the heat is transferred to another heated space, the panel loss will be a source of heat for that space instead. In either case, the magnitude of panel loss should be determined during the design process and panel heat loss to spaces in outside of the room should be kept to a reasonable amount by insulation.

At the design stage, attention should be given to proper water velocity. Water velocity that is too low causes laminar flow, which reduces internal heat exchange. Generally, the heat exchange coefficient within the range of turbulent flows including the transition area is different from that of laminar flows. Approximately we can assume that the average heat exchange coefficient of turbulent flow is about 2200 W/m^2K and that of laminar flow is about 200 W/m^2K. Flow characteristics can be determined by the internal diameter of the pipe, the average velocity of the flow and the kinematic viscosity of the water. The maximum water velocity per loop depends on the selection of pumps. When the design temperature differences between supply and return water are decreased, the design water velocity should be increased. The higher the water velocity the higher the friction loss, and more pump energy is required during operation. Most pipe circuits are designed according to energy criteria with a pressure drop between 10 to 25 kPa.

To prevent the surface condensation problems, the surface temperature of the radiant ceiling can be controlled to be above the dew point temperature. For this purpose, it is necessary to monitor the air temperature and air humidity levels. In a simple manner, the supply water temperature to the panels must be controlled to avoid the possibility of surface condensation. To prevent condensation on the room side of cooling panels, the panel water supply temperature should be maintained at least 1 K above the room design dew-point temperature. This minimum difference is recommended to allow for the normal drift of temperature controls for the water and air systems, and also to provide a factor of safety for temporary increase in space humidity. The most frequently applied dehumidification method is cooling coils. Several chemical dehumidification methods are available to control latent and sensible loads separately. When chemical dehumidification is used, hygroscopic chemical-type dew-point controllers are required at the central apparatus and at various zones to monitor the room dew-point temperatures. When cooled ceiling panels are used with a variable air volume (VAV) system, the air supply rate should be near maximum volume to assure adequate dehumidification before the cooling ceiling panels are activated.

Design processes of hydronic panel systems

Ceiling mounted radiant panels can be integrated into a HVAC system. In such a system, a source of dehumidified ventilation air is required in summer, so this integrated system is classified as an air-and-water system. Also, various amounts of forced air are supplied year round for fresh air supply. When radiant panels are applied for heating only, a ventilation system may be required depending on local codes. Radiant ceiling systems are usually designed in spaces where the suspended acoustical ceiling can be combined with panel heating and cooling. The panels can be designed as small units to fit the space module, which provides extensive flexibility for zoning and control system, or the panels can be arranged as large continuous areas for maximum economy. Some ceiling installations require active panels to cover only a portion of the room and compatible matching acoustical panels for the remaining ceiling area. Panel design requires determining panel area, panel type, supply water temperature, water flow rate, and panel arrangement. Panel performance is directly related to room conditions. Ventilation and dehumidification system also should be designed. Heating and cooling loads may be calculated by procedures in accordance with standards for heating and cooling load calculation, e.g. ISO/FDIS 52016-1", Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures" based on an index such as operative temperature. **Figures 2 and 3** show the design process of cooling and heating operation respectively.

Control of ceiling mounted radiant heating and cooling panels.

ISO 18566-4 includes guidelines on the control of ceiling mounted radiant heating and cooling panels. The requirements specified are applicable only to the components of the heating/cooling systems and the installed elements which are parts of the radiant panels. This standard describes the control of hydronic systems to enable all radiant panel systems to perform as simulated. The design of the control system shall take

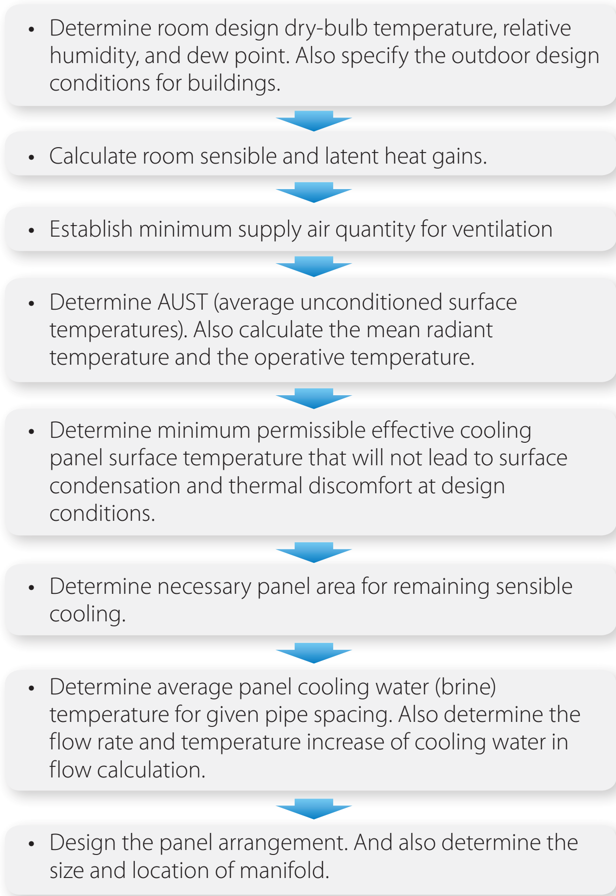


Figure 2. Design process of cooling operation.

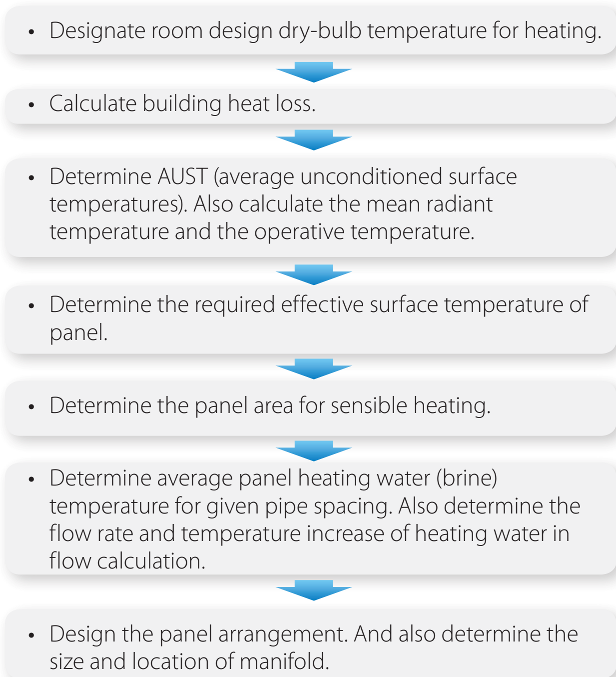
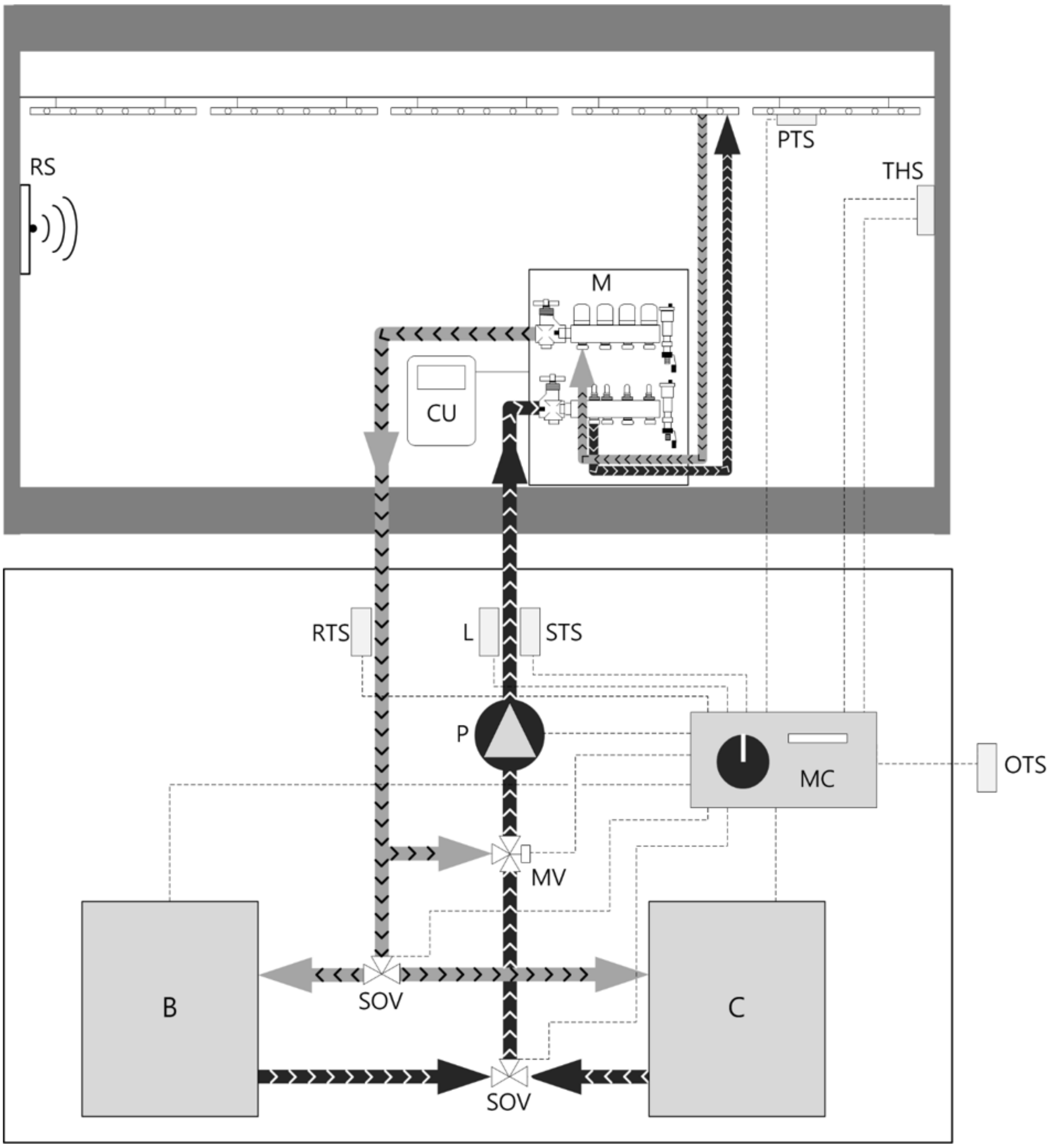


Figure 3. Design process of heating operation.

into account the dynamics of building, its intended use and the effective functioning of the panel system, efficient use of energy and avoiding conditioning the building to full design conditions when not required. The controls shall keep the distribution heat losses as low as possible, e.g. by reducing flow rates and temperatures, when normal comfort temperature level is not required. Control of the system will enable control of the conditioning systems to obtain possible savings of operational costs meeting the required indoor environmental conditions. The control shall ensure that heating and cooling is not occurring at the same time. In order to maintain a stable thermal environment, the control system needs to maintain the balance between supplied energy from the system and the losses/gains of building environment under transient conditions.

Figure 4 shows a diagram of the control principles. The supply water temperature can be controlled by a mixing valve, actuated to maintain the desired condition. In



B	boiler	M	manifold	RS	room sensor
C	chiller	MC	main controller	RTS	return medium temperature sensor
CU	control unit	MV	mixing valve	SOV	shut off valve
PTS	panel temperature sensor	OTS	outside temperature sensor	STS	supply medium temperature sensor
L	limiter	P	Pump	THS	temperature-humidity sensor

Figure 4. Principal diagram of a radiant ceiling panel system for heating and cooling.

the occupied space, there is a sensor for temperature and humidity, which can be used for zone control and/or give input to the control of the mixing valve and provide information to the Building Management System (BMS) to determine space dew point temperature which is necessary to prevent condensation in the building (surface, construction). Outside temperature sensors, supply-return water temperature sensors and in some cases surface temperature sensors are to be installed to influence the control.

The thermal mass and time constant of radiant panel systems are in most cases negligible compared to the thermal mass and time constant of a space. The time response and the thermal storage capacity of systems will depend on the design and materials used for the panels with integrated pipes. Panels with a higher thermal mass or panels with PCM (phase change materials) will have a significant effect if a change in room temperature level is needed. On the other hand, regarding controlling for variations in external climate and internal loads (people, sun, etc.), all the systems are quite fast in response on the room side because of the self-regulating effect.

Conclusions

In principle, ceiling mounted radiant panel systems are able to accommodate varying space sensible loads by controlling panel surface temperature. Heat is transferred from the radiant panel by the heat transfer mechanisms of convection and radiation. ISO 18566 series applies to all types of prefabricated radiant panels with an open air gap that are part of the room periphery such as ceiling, walls and floor. This standard specifies the design, test conditions and methods for the determination of the cooling and heating capacity and control of radiant heating and cooling panels with an open air gap. The ISO 18566 parts are integrated design standards including the design of the entire panel system by providing technical specifications and requirements, test facility and test method for heating and cooling capacity of ceiling mounted radiant panels, the design considerations and design processes, and control of ceiling mounted radiant panels system.

Acknowledgments

The authors would like to acknowledge the contributions of the other experts in the team that is responsible for the preparation of the ISO 18566 in the ISO working group (ISO/TC 205/WG8) to which the preparation of these standards has been assigned. This work was supported by the Technology Innovation Program (10065684, Development of radiant heating and cooling system for reducing the green-house gases in building sector) funded by the Ministry of Trade, industry & Energy (MI, Korea). ■

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ISO DIS 18566-3 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems — Part 3: Design of ceiling mounted radiant panels.

ISO DIS 18566-4 Building Environment Design — Design, test methods and control of hydronic radiant heating and cooling panel systems — Part 4: Control of ceiling mounted radiant heating and cooling panels.

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TEXT: OLLI SEPPÄNEN PHOTOS: FINVAC

FINVAC Building energy seminar attracted 600 participants in September.

FINVAC seminar on energy efficiency of buildings

FINVAC* seminar on energy efficiency of buildings in September attracted 600 top experts in Finland. The audience was a combination of business and public sector people. The focus of the seminar was not only in regulations and technology but also in business. The seminar was organised in cooperation with several Finnish professional organisation and building owners association.

The main speech in the seminar was delivered by the Finnish Minister of the Economic Affairs (in charge also of energy strategy in Finland). He stressed the importance of the construction sector in the Finnish energy strategy, and predicted increase in the energy related activities focusing also on existing building stock.

FINVAC had also invited three prominent speakers from other Nordic Countries, professor Bjarne Olesen from Denmark, Professor Ivo Martinac from Sweden and Professor Natasa Nord from Norway. They all described in detail how the EPBD directive was implemented in their countries. Denmark had the new building regulations already in force but the other countries including Finland are still in the process of finalising the new nearly zero-energy building code. The implementation of EPBD in Nordic countries had several differences but the performance level is quite close to each other. Presentations were extremely useful to the Finnish audience. They also illustrated the need for better coordination of building regulation in the same geographical area.

FINVAC
The Finnish Association of HVAC Societies

* FINVAC is the Finnish member of REHVA, representing over 5 000 HVAC professionals in Finland. Its president is professor Olli Seppänen and secretary general Ms Siru Lönnqvist.

Minister of economic affairs, Mr Olli Rehn (former EU commissioner) (in the middle) arriving to Finlandia Hall with Siru Lönnqvist and Olli Seppänen. Mr Rehn held a presentation on "Role of buildings in Finnish energy strategy"

Nordic speakers, professors Bjarne Olesen, Ivo Martinac and Natasa Nord presented status of the national implementation of nearly zero-energy building regulations.

Real challenges were presented by prof Markku Ollikainen, when he described in detail the results of Paris Climate Change Agreement and its meaning to EU and particularly Finland. Professor Peter Lund from Aalto University presented the potential solution to balance the demand and supply of the energy with various energy conversion and storage technologies. A lively discussion took place on the potential conflict with energy efficiency measures and indoor environment. Finnish authorities did not see it as a problem as energy conservation in Finland is always implemented with good indoor climate first.

An exhibition with close to fifty companies was organised in connection to the seminar. Several REHVA supporters participated like Fläkt Woods, Camfil, Granlund, Grundfos, Halton, Rettig, Somfy, Wilo and Uponor.

The seminar was very well received by the participants. Due to great success of the seminar the board of FINVAC decided to organize the next seminar on October 4th, 2017 in the Finlandia Hall (the same hall were Clima 2007 opening ceremony took place).■

New Secretary General for Danvak

DANVAK –The Danish Society of Heating, Ventilating and Air Conditioning Engineers – will hire a new Secretary General shortly. Michael Mast, who had been the Secretary General for the past six years, left the position on 1st September to devote himself to his job as a lecturer at the Technical University of Denmark (DTU).

Former Communications Manager Zosia Karoline Lav is now acting in the role of Secretary General.

The Board has now initiated the process of finding a new Secretary General who can maintain and develop Danvak's position as a leading provider of courses, conferences, workshops and network for the HVAC Industry and the building sector.

Questions may be directed to chairman Lars Sønderby Nielsen on e-mail: **lsn@hvacconsult.dk**

20 years growing heating, water supply and pool equipment business in Russia

Heating and water supply market in Russia is closely related to various categories of building construction through the categories of systems installed in buildings and the costs involved in such projects. The volume of construction market influences growth of the HVAC equipment and installations market: in 2015 the total value of construction work related to the installation reached 117 bn euro, heating systems accounted for about 58%. In the next 5 years the volume of heating systems installations market is forecasted to grow by 6.6% (CAGR), due to more fragile activity in non-residential construction and renovation of outdated systems.

Financial analysts say that foreign companies which continue the development of business in Russia will be in a better position when the economy starts to recover. Market and economical changes provide an opportunity for proactive players to increase their market share and get new positions in business landscape.

The long-term outlook for the Russian HVAC market is encouraging. Additional support will be provided by the preparations for the World Cup and by the ongoing expansion of modern store formats and shopping centres, particularly in the cities with fewer than 500,000 residents.

Aquatherm Moscow is the leading B2B show in Russia and the CIS countries for developing heating, water supply, engineering systems and pool equipment business. The top-of-the-range event each year opens construction season providing an opportunity to showcase products and technologies to thousands of local buyers looking for the new solutions. In 2016, 651 exhibitors from 30 countries presented 961 HVAC & Pool product solutions at 34 000 sqm of total exhibition space.

Over 150 Russian, European, Asian and Middle Eastern producers exhibited at the show for the first time. The exhibition gathered world market leaders and industry newcomers who had negotiations with over 26 thousand professional visitors.

The international status of the show reflects the interest of market players to the Russian market: annually the show presents the expositions officially supported by international trade and industry organisations, including REHVA, IPC team, E.V.A.E.T., Amec Ascon, BSW, WSM, Pro Brixia, and BDH.

The upcoming event will deliver the strongest and most efficient opportunities for international companies to enter one of the largest European HVAC markets and improve sales network with thousands of distributors, wholesalers, retailers, design, construction and engineering companies.

Prospective place for growing business

For 2017 edition, the show is proud to present the global HVAC leaders: world-known German, Italian, Spanish, Korean, Turkish and Chinese brands which are confident in the Russian market potential.

The show profile covers the whole range of heating and water supply products with a special focus on pool, and bathroom equipment players that welcome the companies to present their products on the booming and demanding for novelties markets.

- **Significant exposition of World of Water & Spa** is a meeting point for professionals of pools and spas sector. Being approx. 90% imported, the section related products are more than relevant for the high demand of domestic market in the world experience. The section is considered to be the only specialised B2B platform for this industry in Russia.

- **New Energy project** supports the state programme for renewable and efficient energy sources and the increasing propensity to implement energy-efficient solutions in commercial structures and in all other buildings. The project participants showcase their energy and resources saving appliances and equipment to the Russian customers' interested in purchasing equipment featured with the energy-efficient technologies.

Promotion of fresh market offers

Special promotional programmes help the first-time exhibitors and market novelties to be directly introduced to the Aquatherm Moscow audience. Being highlighted in the exhibition materials and on the web-site they are promoted among the key buyers long before the exhibition starts. ■

Aquatherm Moscow will be held on 7 – 10 of February 2017 in Crocus Expo, Moscow.

Aquatherm Moscow is the largest international event in Russia and CIS in the industry of domestic and industrial heating, water supply, engineering and plumbing systems, ventilation, air-conditioning and equipment for pools, saunas and spas.

The benchmark event connects producers and brand representatives all over the globe with local distributors, wholesalers, dealers, manufacturers, engineering, construction, housing and property companies to maximize their opportunities by generating business leads, meeting partners, exchanging best practices and learning the latest industry trends.

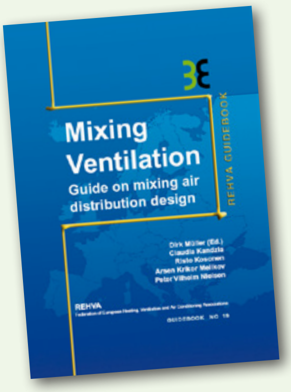
About the organisers

Reed Exhibitions is the world leader in organising events. Every year Reed Exhibitions run over 500 events in 43 countries, bringing together over 7 mln active event participants worldwide. With over 3700 employees in 40 offices around the globe the company serves 43 industries worldwide. A unique network of international sales group provides support to exhibitors on export markets.

The ITE Group is one of the world's leading exhibition organisers, it is ranked 6th in the world and 1st in Russia. The company is developing dynamically, and for 20 years established 20 offices worldwide. In Russia, ITE offices operate in five cities (Moscow, St. Petersburg, Krasnodar, Ekaterinburg, Novosibirsk) and hold over 150 events annually. ■

Active and Passive Beam Application Design Guide for global application

Active and Passive Beam Application Design Guide 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. The systems are simple to operate and maintain. This new guide 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.



REHVA Guidebook on 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.

REHVA - **Federation of European Heating, Ventilation and Air Conditioning Associations**
40 Rue Washington, 1050 Brussels – Belgium | Tel 32 2 5141171 | Fax 32 2 5129062 | www.rehva.eu | info@rehva.eu

ISH Shanghai & CIHE 2016 ends in acclaim, demonstrating the great potential of Eastern and Central China's HVAC market

Exhibitors commended show for its high business creation potential. Air-source heat pump technologies and home comfort were event focal points.

Dedicated to the HVAC market in Eastern and Central China, the fifth edition of ISH Shanghai & CIHE – Shanghai International Trade Fair for Heating, Ventilation & Air-Conditioning was successfully held from 31 August – 2 September 2016 in Hall W1 of the Shanghai New International Expo Centre (SNIEC). The show was jointly organised by Messe Frankfurt (Shanghai) Co Ltd, Beijing B&D Tiger Exhibition Co Ltd, Shanghai Zhanye Exhibition Co Ltd and the China Council for the Promotion of International Trade (CCPIT) – Shanghai Pudong Sub-Council.

Mr Richard Li, General Manager of Messe Frankfurt (Shanghai) Co Ltd, expressed: "After five years of development, ISH Shanghai & CIHE has become a sophisticated fair that attracted 16,527 visitors (2015: 15,726, +5%) and hosted 192 exhibitors this year. Among those exhibitors were companies from the popular European Pavilion and the new Premium Brand Zone. Exhibitors commended the visitor quality while buyers appreciated what they found onsite. In addition, the concurrent events were well-received and generated so much interest that many sessions were crowded with standing attendees. This strong attendance demonstrates that there is great market potential and the show is a proven annual professional trade platform for the HVAC market in Eastern and Central China."

Mr Li Hongbo, General Manager at Beijing B&D Exhibition Co Ltd, added: "Winters in Eastern and Central China are getting colder and colder. This fact coupled with rising spending power in the region is making the demand for greater home comfortability soar. The HVAC market is blossoming here. We will stay close with market trends and continue to connect suppliers with buyers through ISH Shanghai & CIHE, as well as introduce the latest products and technologies to the Chinese market."

Being a member event of the "Intelligent Green Building – IGB" exhibition platform (Shanghai edition), ISH Shanghai & CIHE ran concurrently with three other fairs: Shanghai Intelligent Building Technology, Shanghai Smart Home Technology and Shanghai International Lighting Fair. Collectively, these events provided total solutions for energy-efficient building technologies to Eastern and Central China. The exhibitions spanned across 40,000 sqm covering halls W1, W3, W4 and W5, while gathering over 600 exhibitors and 52,000 trade visitors.

Exhibitors commended ISH Shanghai & CIHE for its high business creation potential

Given rising demand for heating solutions in Eastern and Central China, many overseas and domestic enterprises use ISH Shanghai & CIHE as a springboard to penetrate the region's promising HVAC market. The European Pavilion joined for the third time this year and several leading local exhibitors participated in the new Premium Brand Zone, where unique booth designs were applied and products were showcased in a designated display area.

Thermotec was one of the exhibitors at the European Pavilion. Mr Lu Xiaohua, spokesman for the brand, said: "It is our third year participating in the European Pavilion at ISH Shanghai & CIHE. Our results were fruitful in the past years and so we came back again this year. Through exhibiting at the show, potential customers are able to learn more about our company and products. We can also network with fellow industry peers and learn from their product trials. Recent winter temperatures in Eastern and Central China have reached as low as -5 degrees Celsius and various heating solutions such as those using water and electricity are being applied. The market is emerging and my outlook is positive so I will come back to exhibit again next year."

This year, many exhibitors were happy with the quality and quantity of visitors, particularly the high concentration of agents and distributors. Exhibitors also reacted positively to the strong potential for forming business deals at the fair.

Mr Paolo Chen, General Manager of Italtherm (Beijing) Heating Technology Co Ltd – a renowned Italian exhibitor, expressed: "The wall-hang boiler market has the highest potential for growth in Eastern and Central China. As more piping systems are installed and residents earn higher incomes, people will ask for more comfortable heating solutions. Therefore, we are introducing our standard wall-hang boilers with heat efficiency at 92 – 94%, as well as our condensing boilers which are commonly used in Europe. Our main objective is to meet with distributors and the results we have achieved are better than expected. The show helped us to promote the advantages of our Italian brand to distributors and end-users from Shanghai, Zhejiang and Jiangsu."

Having made its overseas exhibition debut at ISH China & CIHE in Beijing earlier this year, Daian Service Inc from Japan also joined ISH Shanghai & CIHE. Mr Hiroshi Yonemura, Deputy Manager of the company's Overseas Business Planning & Development Department, expressed: "We are a manufacturer who is new to the Chinese market. Therefore, we need to establish a distributor network to develop here. I am delighted that there were a lot of distributors and agents at the fair. Business opportunities at the show are abundant and I received enquiries for a container order almost every day. Additionally, the service provided by the organiser was very good and I will definitely return again."

System integration was the key sales point of Menred Group Co Ltd. Ms Zhang Lingli, Manager of the company's Marketing Department, said: "Exceeding our expectations was the popularity of our fresh air products this year. Visitor flow to our booth is always high, so we participate in both the Beijing and Shanghai shows every year. Nowadays, turnover is no longer our main focus at the exhibition, rather brand promotion is. Our objective is to find more distributors of end-users so we can introduce our products to real consumers."

Visitors also gave positive comments about their visits. A commonality between them was that they were pleased with the innovative products and technologies introduced by the European Pavilion and imported brands. Tianjin Yilan Energy-efficient Technology Co Ltd, a distributor of end-of-line products, plans to transform itself into a system integrator. Mr Li Guanglin, General Manager of the company, said: "The integration of air conditioning with floor heating is the current trend and so I came to the show to learn more about this. There are plenty of imported brands offering products with quality that is much higher than those made domestically, such as flooring heating and manifolds. I need to learn more about these products so I can introduce them to my clients in the future."

Air-source heat pump technologies and home comfort were event focal points

The informative concurrent programme was one of the show highlights, providing the latest market intelligence and ample networking opportunities. Speakers and attendees agreed that the heating market in Eastern and Central China has huge potential. As such, air-source heat pump technologies and home comfort were the focal points of the programme.

Mr Cooper Zhao, Deputy Secretary General of the China Heat Pump Alliance and the Heat Pump Committee of the China Energy Conservation Association, organiser of the "Shanghai International HVAC Forum – Heat Pump Technologies, stated: "The Yangtze River Delta is the most populated and economically developed area in China. The need for heating is out there but there is no sophisticated piping network for central heating. Therefore, in the long run, air-source heat pumps (ASHP) will be a big market with high potential here. The full audience indicated that the whole industry supply chain, from manufacturers and distributors to engineers and end-of-line enterprises, recognises that ASHP is the trend. These players joined the forum to learn for better design, manufacturing and sales of ASHP solutions."

The seminar on "Floor Air Supply System Application Technologies", co-organised by the renowned industrial portal hvac8.com, was another event that recorded strong attendance. Coming from the Technical Department of Dakin (China) Investment Co Ltd, seminar attendee Mr Zheng Lei noted: "The seminar mainly covered the design and installation of floor air supplies, and their actual applications in the market, which interested me the most. The presentations by speakers helped me to expand my thinking. I learned new techniques and obtained the latest market intelligence. This kind of technical seminar can draw many professional visitors and exhibiting installers to the show."

Additionally, there was an interactive brainstorming session on Tenement Home Comfort hosted by Mr Tian Bo, a renowned HVAC WeChat group leader. He said: "The brainstorming session discussed ways to increase product efficacy and amenity of air conditioning, heating and water purification in older homes. This emerging market has huge potential. The room where the session was held was packed with a full audience made up of both exhibitors and visitors. One after another, manufacturers, system integrators and system providers alike took to the floor with their ideas. I hope the session delivered new inspiration, ways of thinking and business opportunities to the industry."

The next ISH Shanghai & CIHE will be held from 5 – 7 September 2017 at Shanghai New International Expo Centre. It is headed by the biennial ISH event in Frankfurt, Germany, which is the world's leading trade fair for the Bathroom Experience, Building, Energy, Air-Conditioning Technology and Renewable Energies. The mother event will take place from 14 – 18 March 2017. Moreover, a new addition to the ISH exhibition profile is ISH India powered by IPA, which will run from 23 – 25 February 2017 at the India Expo Centre. For more information, please visit **www.ish.messefrankfurt.com**.

As for the next edition of ISH China & CIHE – China International Trade Fair for Heating, Ventilation, Air-Conditioning Sanitation and Home Comfort System, it is scheduled to be held at the New China International Exhibition Center in Beijing, China from 18 – 20 May 2017. For more information, please visit **www.ishc-cihe.com** or email **info@ishc-cihe.com**.

Background information on Messe Frankfurt

Messe Frankfurt is one of the world's leading trade fair organisers, generating around €648 million in sales and employing 2,244 people. The Messe Frankfurt Group has a global network of 30 subsidiaries and 55 international Sales Partners, allowing it to serve its customers on location in 175 countries. Messe Frankfurt events take place at approx. 50 locations around the globe. In 2015, Messe Frankfurt organised a total of 133 trade fairs, of which more than half took place outside Germany.

Comprising an area of 592,127 square metres, Messe Frankfurt's exhibition grounds are home to ten exhibition halls. The company also operates two congress centres. The historic Festhalle, one of the most popular venues in Germany, plays host to events of all kinds. Messe Frankfurt is publicly owned, with the City of Frankfurt holding 60 percent and the State of Hesse 40 percent.

For more information, please visit our website at **www.messefrankfurt.com**

New Eurovent Certification Programme – Ventilation Duct

Paris – Sept 15th, 2016.

Eurovent Certita Certification is pleased to announce the launch of a new certification programme for Ventilation Ducts (DUCT).

The DUCT programme has been developed in 2015-2016 with the support of a dedicated launching committee. The first release of the Operational Manual (OM) and Rating Standards (RS) apply to rigid and semi-rigid ventilation ductwork systems divided into the following sub-programmes:

- Rigid metallic ductwork systems with circular cross-section (DUCT-MC);
- Rigid metallic ductwork systems with rectangular cross-section (DUCT-MR);
- Semi-rigid non-metallic ductwork systems predominantly made of plastics (DUCT-P);

All ranges of products that fall into the relevant sub-programme scope and are promoted by the Applicant/Participant shall be certified. The "certify-all" principle applies not only to Europe but to all markets.

The certification programme is based on product performance testing by independent laboratories as well as manufacturing facility auditing.

The product performance testing will enable the verification of the following ratings accuracy:

- Air tightness class (all sub-programmes)
- Positive and negative pressure limits (all sub-programmes)
- Dimensions (DUCT-MC and DUCT-MR)
- Minimum and maximum service temperatures (DUCT-P)
- Resistance to external pressure (DUCT-P)

Air leakage and strength testing shall be conducted in accordance with EN 12237:2003 (DUCT-MC and DUCT-P) or EN 1507:2006 (DUCT-MR).

For tests related to service temperatures and resistance to external pressure (DUCT-P) the method is described in the Rating Standard RS 2/C/004P-2016.

The following schedule is being foreseen:

- Signing of agreement by manufacturers for DUCT programme (contact apply@eurovent-certification.com). There is no deadline as this is a voluntary registration.
- April 2017: Publication of certified data on Eurovent Certification website foreseen on 30 April 2017 for manufacturers signing the license agreement before 31 October 2016.

Eurovent Certita Certification is a major European certification body in the field of HVAC-R, operating 38 certification programs and generating about € 12 million in turnover. Eurovent Certita Certification provides voluntary third part certification services on the full range of HVAC-R products, whatever their final use, either in residential domestic buildings or in industrial facilities for instance. Eurovent Certita Certification is offering various certification schemes tailored to the needs of manufacturers and stakeholders on their specific markets. It focuses on certifying products' performances as well as data needed to implement regulations. The main quality marks currently proposed are the marks "Eurovent certified performance", NF, CSTBat, and the European Keymark.

On a market ever more demanding in terms of energy performances and environmental challenges, Eurovent Certita Certification supplies certified data at a European level and provides the needed confidence.

Certification schemes for both domestic & industrial facilities:

Indoor climate:	Heat pumps, air conditioners, liquid chilling packages, VRF, rooftop …
Ventilation & Air quality:	Radiators, fan coils, solar collectors and heaters, heating appliances using liquid or solid fuels, mobile liquid fuel heaters, chilled beams …
Refrigeration & Food cold chain	Cooling and heating coils, cooling towers, heat exchangers, milk coolers, condensing units, compressors, refrigerated display cabinet...

For more information:

Nadia Cherré – Marketing & Communication manager

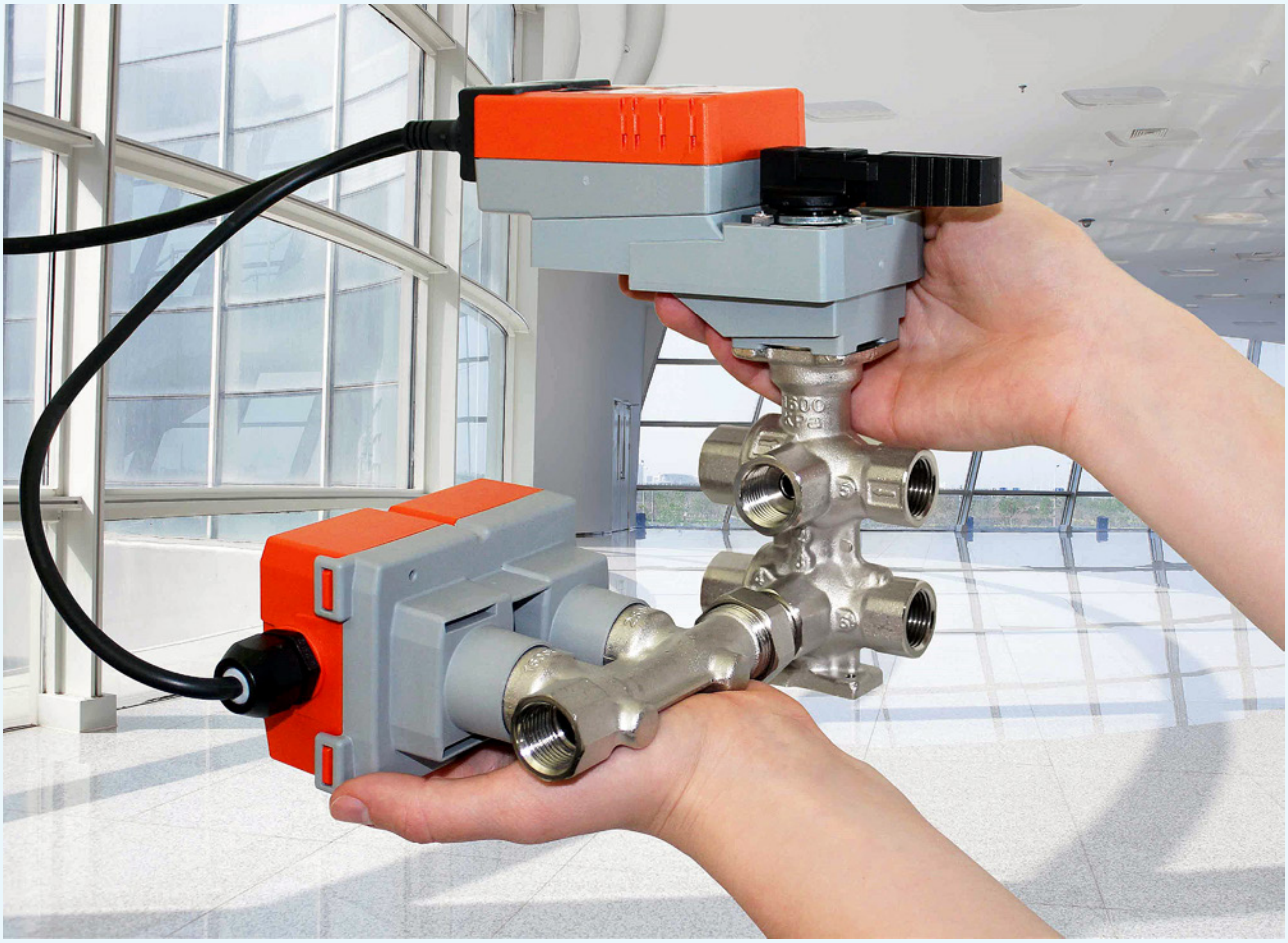
Tel: 33 (0)1 75 44 71 36 - **n.cherre@eurovent-certification.com**

Check performances on line **www.eurovent-certification.com, www.certita.fr**

Belimo ZoneTight™

Two become one for increased efficiency

The electronic pressure-independent 6-way zone valve from the Belimo ZoneTight™ product family combines two tried and tested valves in one unit. It brings together the good planning reliability and efficiency of the electronic pressure-independent valve (EPIV) and the ease of installation of the 6-way characterised control valve.



The electronic pressure independence allows the consulting engineer to quickly and easily configure the valve to the volumetric flow required. There is no need to calculate the k_{vs} value, which gives a high level of certainty during planning.

During installation, the electronic pressure-independent 6-way zone valve takes over the function of up to four 2 port valves. No balancing valves need to be fitted.

The integrated flow rate measurement and the electronic flow rate control allow the desired amount of water to be ensured for both sequences during full load and partial load. The respective measured values can also be called up as real time information, producing optimum operating conditions.

The characterised control valve closes with absolutely no leaks (leakage rate A according to EN12266-1), preventing energy losses, and the integrated pressure relief function of the electronic pressure-independent 6-way zone valve ensures maximum system safety.

Can be controlled conventionally or by Belimo MP-Bus®, BACnet MS/TP and Modbus. Furthermore the valve can be put into operation and checked by a smartphone via NFC (Near Field Communication).

More information: **www.belimo.eu**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NEW REHVA REPORT 6

Building and HVAC system performance in practice

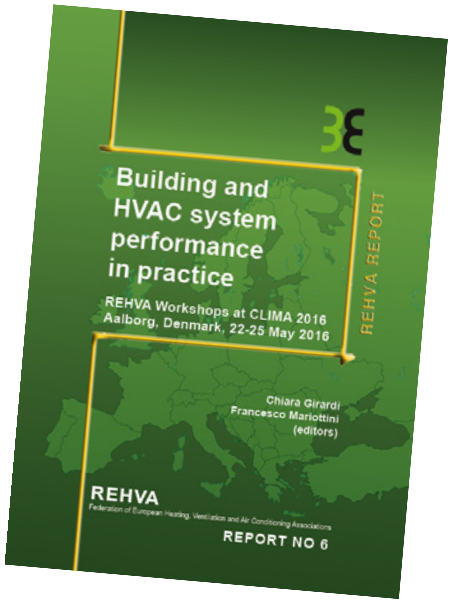
REHVA Workshops at CLIMA 2016 Aalborg, Denmark, 22–25 May 2016

The 6th REHVA Report deals with the outcomes of the technical workshops organised during our triennial flagship event, the CLIMA2016 REHVA World Congress.

REHVA Board of Directors and REHVA Team would like to express their gratitude to our hosts, Lars Nielsen, Michael Maast, and the DANVAK team, as well as Per Heiselberg and his team from Aalborg University for their excellent work that contributed to the great success of the Congress.

REHVA organised 25 Technical Workshops during CLIMA 2016. The objective of these workshops was to present advanced technologies and tools, European projects and the work of the REHVA Task Forces that are developing new Guidebooks.

The workshops were practical and interactive sessions with international experts presenting best practices from across Europe. They generated active discussions between the speakers and the audience. This year, REHVA gave the floor to its Supporters (Swegon; Eurovent Association; Eurovent Certita Certification; Grundfos; Belimo; ES-SO), international cooperation partners (SHASE; CCHVAC; SAREK). Work undertaken in European research projects (PROF/TRAC, QUANTUM, Cheap-GSHPs; QUALICHeCK), and by REHVA Task Forces coordinated by the REHVA Technical and Research Committee was also presented. The Task Forces will go on to use the workshop outcomes to develop European guidelines for improving building energy performance and indoor environment quality.



REHVA would like to express our sincere gratitude to the workshop chairs and speakers for their valuable work and for their contributions in finalising this Report.

The REHVA Technical Workshops and this booklet were supported by several companies and organizations. REHVA thanks all of them for their contribution and invites them to continue with our fruitful co-operation.

Visit REHVA's eShop to purchase this new publication
http://www.rehva.eu/?id=6

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

Events in 2016 - 2017

Conferences and seminars 2016

October 23-26	IAQVEC 2016: international conference on indoor air quality, ventilation & energy conservation in buildings	Seoul, South Korea	https://goo.gl/Ug7n1s
November 8 - 12	CCHVAC Conference	Hainan, China	https://goo.gl/EBN09E
November 30 - Dec. 2	47th International HVAC&R Congress and Exhibition	Belgrade, Serbia	http://goo.gl/n5QKjS

Conferences and seminars 2017

January 28 - Feb. 1	ASHRAE Winter Conference	Las Vegas, NV, USA	https://goo.gl/IdvOhv
February 7-10	Aquatherm Moscow	Crocus Expo, Moscow, Pavilion 3, Halls 13-15	https://goo.gl/0R0bGS
February 14-17	Aquatherm Novosibirsk	Novosibirsk Expo Centre	https://goo.gl/CNvxyD
March 1-3	World Sustainable Energy Days 2017	Wels, Austria	https://goo.gl/of0tje
April 19-22	Teskon+Sodexis	Izmir, Turkey	https://goo.gl/Z85SXj
April 19-21	Aquatherm St. Petersburg	EXPOFORUM, Pavilion G, St. Petersburg, Russia	https://goo.gl/hJJz5i
May 10-11	50th International Congress "Beyond NZEB retrofit of existing buildings"	Matera, Italy	https://goo.gl/V6abmR
May 10-13	Sodex Ankara	Ankara, Turkey	https://goo.gl/afP9qP
May 12-13	Climamed 2017 Conference "Historical buildings retrofit in the Mediterranean area"	Matera, Italy	https://goo.gl/DpxDZg
May 15-18	12th IEA International Heat Pump Conference	Rotterdam, The Netherlands	https://goo.gl/hRMY16
August 7-9	Building Simulation 2017	San Francisco, California, USA	https://goo.gl/XjbVXA

Exhibitions 2017

January 30 - Feb. 1	2017 AHR Expo	Las Vegas, NV, USA	https://goo.gl/pUdVal
February 23-25	ACREX 2017	Delhi, India	https://goo.gl/S8aVbQ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At Swegon we take indoor climate quality very seriously. You have probably not seen our products, but you have certainly noticed them – innovated to be experienced, designed not to be seen. We work for the health and comfort of people in buildings by delivering optimal indoor climate solutions.
We are Swegon – The indoor climate company

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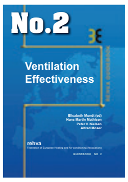
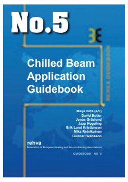
Federation of European Heating, Ventilation and Air Conditioning Associations

REHVA GUIDEBOOKS

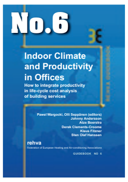
REHVA Guidebooks are written by teams of European experts



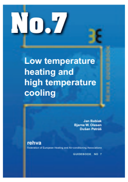
Ventilation Effectiveness. Improving the ventilation effectiveness allows the indoor air quality to be significantly enhanced without the need for higher air changes in the building, thereby avoiding the higher costs and energy consumption associated with increasing the ventilation rates. This Guidebook 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.



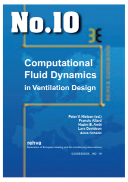
Chilled Beam Cooling. Chilled beam systems are primarily used for cooling and ventilation in spaces, which appreciate good indoor environmental quality and individual space control. Active chilled beams are connected to the ventilation ductwork, high temperature cold water, and when desired, low temperature 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.



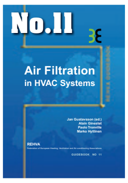
Indoor Climate and Productivity in Offices. This Guidebook shows how to quantify the effects of indoor environment on office work and also how to include these effects in the calculation of building costs. Such calculations have not been performed previously, because very little data has been available.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



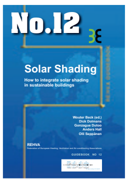
Low Temperature Heating And High Temperature Cooling. This Guidebook describes the systems that use water as heat-carrier and when the heat exchange within the conditioned space is more than 50% radiant. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in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



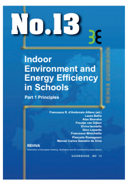
Computational Fluid Dynamics in Ventilation Design. CFD-calculations have been rapidly developed to a powerful tool for the analysis of air pollution distribution in various spaces. However, the user of CFD-calculation should be aware of the basic principles of calculations and specifically the boundary 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.



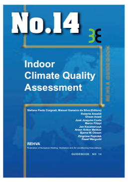
Air Filtration in HVAC Systems. This Guidebook will help the designer and user to understand the background and criteria for air filtration, how to select air filters and avoid problems associated with hygienic and other conditions at operation of air filters. The selection of air filters is based on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



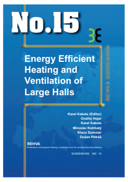
Solar Shading – ***How to integrate solar shading in sustainable buildings.*** Solar Shading Guidebook gives a solid background on the physics of solar radiation and its behaviour in window with solar shading systems. Major focus of the Guidebook is on the effect of solar shading in the use of energy 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.



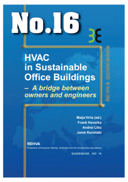
Indoor Environment and Energy Efficiency in Schools – ***Part 1 Principles.*** School buildings represent a significant part of the building stock and also a noteworthy part of the total energy use. Indoor and Energy Efficiency in Schools Guidebook describes the optimal design and operation of schools with respect to low energy cost and performance of the students. It focuses particularly on energy efficient systems for a healthy indoor environment.



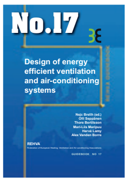
Indoor Climate Quality Assessment. This Guidebook gives building professionals a useful support in the practical measurements and monitoring of the indoor climate in buildings. Wireless technologies for measurement and monitoring have allowed enlarging significantly number of possible applications, especially in existing buildings. The Guidebook illustrates with several cases the instrumentation.



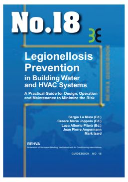
Energy Efficient Heating and Ventilation of Large Halls. This Guidebook is focused on modern methods for design, control and operation of energy efficient heating systems in large spaces and industrial halls. The book deals with thermal comfort, light and dark gas radiant heaters, panel radiant heating, 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.



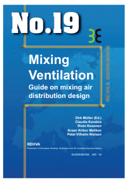
HVAC in Sustainable Office Buildings – ***A bridge between owners and engineers.*** This Guidebook discusses the interaction of sustainability and heating, ventilation and air–conditioning. HVAC technologies used in sustainable buildings are described. This book also provides a list of questions to be asked in various phrases of building's life time. Different case studies of sustainable office buildings are presented.



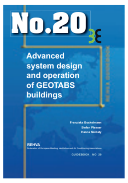
Design of energy efficient ventilation and air-conditioning systems. This Guidebook covers numerous system components of ventilation and air-conditioning systems and shows how they can be improved by applying the latest technology products. Special attention is paid to details, which are often overlooked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



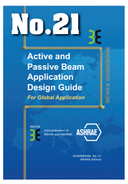
Legionellosis Prevention in Building Water and HVAC Systems. This Guidebook is a practical guide for design, operation and maintenance to minimize the risk of legionellosis in building water and HVAC systems. It is divided into several themes such as: Air conditioning of the air (by water – humidification), 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 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. The systems are simple to operate and maintain. This new guide 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.

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