Energy in Buildings and Communities Programme

International Energy Agency

Ventilative Cooling Case Studies

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EBC is a programme of the International Energy Agency (IEA)

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the Energy in Buildings and Communities (EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA-EBC Programme was known as the Energy in Buildings and Community Systems Programme, ECBCS.)

The research and development strategies of the IEA-EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. The research and development (R&D) strategies of IEA-EBC aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five focus areas for R&D activities:
- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA-EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA-EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA-EBC Executive Committee, with completed projects identified by (*):

Annex 1: Load Energy Determination of Buildings (*)
Annex 2: Ekistics and Advanced Community Energy Systems (*)
Annex 3: Energy Conservation in Residential Buildings (*)
Annex 4: Glasgow Commercial Building Monitoring (*)
Annex 5: Air Infiltration and Ventilation Centre
Annex 6: Energy Systems and Design of Communities (*)
Annex 7: Local Government Energy Planning (*)
Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9: Minimum Ventilation Rates (*)
Annex 10: Building HVAC System Simulation (*)
Annex 11: Energy Auditing (*)
Annex 12: Windows and Fenestration (*)
Annex 13: Energy Management in Hospitals (*)
Annex 14: Condensation and Energy (*)
Annex 15: Energy Efficiency in Schools (*)
Annex 16: BEMS 1- User Interfaces and System Integration (*)
Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18: Demand Controlled Ventilation Systems (*)
Annex 19: Low Slope Roof Systems (*)
Annex 20: Air Flow Patterns within Buildings (*)
Annex 21: Thermal Modelling (*)
Annex 22: Energy Efficient Communities (*)

Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25: Real time HVAC Simulation (*)
Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28: Low Energy Cooling Systems (*)
Annex 29: Daylight in Buildings (*)
Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis & Evaluation Methods (*)
Annex 54: Integration of Micro-Generation & Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance & Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy & CO_2 Emissions Optimization in Building Renovation
Annex 57: Evaluation of Embodied Energy & CO_2 Equivalent Emissions for Building Construction
Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)
Annex 59: High Temperature Cooling & Low Temperature Heating in Buildings
Annex 60: New Generation Computational Tools for Building & Community Energy Systems
Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings
Annex 62: Ventilative Cooling
Annex 63: Implementation of Energy Strategies in Communities
Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles
Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems
Annex 66: Definition and Simulation of Occupant Behavior in Buildings
Annex 67: Energy Flexible Buildings
Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings
Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings
Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale
Annex 71: Building Energy Performance Assessment Based on In-situ Measurements
Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings
Annex 73: Towards Net Zero Energy Public Communities
Annex 74: Energy Endeavour
Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)
Working Group - Survey on HVAC Energy Calculation Methodologies for Non-residential Buildings

Abbreviations

Table 1 List of frequently used abbreviations

Abbreviations	Meaning
AT	Austria
BE	Belgium
CN	China
FR	France
IE	Ireland
IT	Italy
JP	Japan
NO	Norway
PT	Portugal
POF	Percentage Opening Area to Floor Area ratio
UK	United Kingdom
VC	Ventilative Cooling

Foreword

This book of case studies is based on the work of IEA-EBC Annex 62 “Ventilative Cooling” and the research findings of the participating countries.

The publication is an official Annex report. Beside this guide the Annex has produced the following official reports:

- Ventilative Cooling Design Guide
- Ventilative Cooling Source Book
- Ventilative Cooling Recommendations for Standards and Legislation
- Ventilative Cooling Summary Report

All reports can be found on the website of IEA-EBC, www.iea-ebc.org

This book is aimed for both architects and engineers to support the design of ventilative cooling systems. It is the hope, that it will be helpful for both architects, engineers and professional building owners in their search for innovative and energy-efficient ventilative cooling solutions.

Per Heiselberg

Operating Agent, Aalborg University, Denmark

Acknowledgement

The material presented in this publication has been collected and developed within an Annex of the IEA Technology Collaboration Programme: Energy in Buildings and Communities, Annex 62 “Ventilative Cooling”.

The publication is the result of an international joint effort conducted in 15 countries. All those who have contributed to the project are gratefully acknowledged. A list of participating institutes can be found on page 33.

On behalf of all participants, the members of the Executive Committee of the IEA Technology Collaboration Programme Energy in Buildings and Communities as well as the funding bodies are gratefully acknowledged.

Executive Summary

Introduction

Examples of well documented case studies that use ventilative cooling (VC) to reduce the energy demand for cooling or overheating risk in new and refurbished buildings are valuable to the energy in buildings community. This report and associated brochures contains such examples and provides details on the design, control, operation and performance of the VC systems.

Objectives and contents of the Summary case study report

The present report aggregates and summarises all 15 case study buildings collected in subtask C of IEA-EBC Annex 62. This summary presents the key characteristics and information about the design, simulation and operational performance of the case study buildings. In addition, it compares the use of different VC solutions in different buildings and different climates and provides a general introduction to the case study brochures where more detailed information is contained for each building.

Scope of the brochures

The case studies are presented in brochure format. Each brochure contains information in a standardised format including tabulated data such as general information, building properties, component dimensioning, design criteria, design stage simulations, control strategy and so forth. There are three main parts to each brochure, the first is a summary of the information about the building and the VC system including details about the selected control strategy and the design process. This section has a standard layout across all brochures. The second part contains performance evaluation information which has results of various studies that are unique to each case study. The last part contains lessons learned from the building including design and construction stages and operation stages.

Table of content

1. Introduction

Within the IEA-EBC Annex 62 well documented case studies using VC from participating country members of the IEA were collected and are presented in specific case study brochures available on the IEA-EBC Annex 62 website. These case studies were selected and included because of the availability of rich information regarding their design, construction and operational performance. The intention was to present a detailed factsheet that explained the rationale for the strategies chosen as well as the buildings in which they are used. The verified performance of the VC solutions was also a prerequisite to the inclusion of a case study. Table 2 summarises the sections of the case study brochure and where to find certain information.

Table 2: Case Study Brochure Structure

Section	Title	Information
1	Introduction, Local Climate & Key Features	Summary details and key characteristics of the building including the local climate
2	Building Information & Design Influences	Layout and section drawings, thermophysical properties and design influences
3	Energy Systems Overview	Summary overview of the mechanical and electrical energy systems
4	Ventilative Cooling Principles & Components	Component dimensioning, outline of VC strategy and solutions
5	Control Strategy Overview	Outline of the VC control strategy, description of operating modes and variables used
6	Design Criteria & Simulation	Details of design stage simulations tools and results, design criteria selected
7	Performance Evaluation	Project specific operational performance evaluations
8	Lessons Learned	Key outcomes and recommendations from design, construction and operation
9	References & Project Contacts	Relevant literature and contact information

The report gives an overview of the characteristics and lessons learned from investigated case studies. It summarises the features of the various case studies including the building characteristics, VC strategies and systems, design criteria and approach and lessons learned. It presents results from performance evaluations for selected case studies. The 15 case studies that are analysed in this report are located in 10 countries. Three were completed in 2014, four in 2013, two in 2012, four in 2011 with the two remaining case studies in 2003 and 2007. Over 85% of case studies were built after 2010. There are three office buildings, five educational buildings, four residential, one mixed use and one kindergarten. Eight of the case studies have rural surroundings and seven have urban surroundings. Four case studies were refurbishment projects. Table 3 shows the range of climate regions represented within the case studies while Table 4 summarises key categorical information about the case study buildings.

Table 3: Variation in climate regions for all case study buildings. (Please refer to the Köppen - Geiger (KG) climate classification system for details on KG abbreviations in column 1)

KG	General Description	Qty	Locations
Cfb	Temperate with warm summers and no dry season	6	Cork (IE) Ernstbrunn (AT) Waregem (BE) Ghent (BE) Verrieres-le-Buisson (FR) Bristol (UK)
Cfa	Temperate, hot summers and no dry season	2	Changsha (CN) Hayama (JP)
Dfb	Cold with warm summers and no dry season	3	Stavern (NO) Trondheim (NO) Innsbruck (AT)
Dfc	Cold with no dry season and cold summer	1	Larvik (NO)
Csa	Temperate with dry, hot summers	2	Sicily (IT) Lisbon (PT)

Table 4: Building Type, size and year of completion for all case studies

No	Country	Building	Type	Year (New -N or Refurb - R)	Floor Area m^2	Ventilation Strategy
01	IE	zero2020	Office	2012$^{(R)}$	223	Natural
02	NO.1	Brunla Primary school	Education	2011$^{(R)}$	2500	Hybrid
03	NO.2	Solstadbarnehage	Kindergarten	2011$^{(N)}$	788	Hybrid
04	CN	Wanguo MOMA	Residential	2007$^{(N)}$	1109	Mechanical
05	AT.1	UNI Innsbruck	Education	2014$^{(R)}$	12530	Hybrid
06	AT.2	wkSimonsfeld	Office	2014$^{(N)}$	967	Hybrid
07	BE.1	Renson	Office	2003$^{(N)}$	2107	Natural
08	BE.2	KU Leuven Ghent	Education	2012$^{(N)}$	278	Hybrid
09	FR	Maison Air et Lumiere	House	2011$^{(N)}$	173	Natural
10	IT	Mascalucia ZEB	House	2013$^{(N)}$	144	Hybrid
11	JP.1	Nexus Hayama	Mixed Use	2011$^{(N)}$	12836	Natural
12	JP.2	GFO	Mixed Use	2013$^{(N)}$	399000	Hybrid
13	PT	CML Kindergarden	Education	2013$^{(N)}$	680	Natural
14	UK	Bristol University	Education	2013$^{(R)}$	117	Mechanical
15	NO.3	Living Lab	Residential	2014$^{(N)}$	100	Hybrid

2. Building design

The case studies demonstrate a range of different building characteristics. Some of these characteristics are developed in response to the decision to use VC while others are the reason VC was adopted. The following sections summarise design influences, building morphology and thermal properties of the case studies.

2.1. Design Influences

A range of factors can have varying levels of influence on building design when adopting VC. From a review of the case studies, the importance of different parameters on the selection of VC components is summarized in Table 5. For each case study, the relative importance of different factors on the design of the building was ranked qualitatively using High, Medium or Low classifications. In this table we can see that lower initial costs and lower energy costs were consistently important design influences across most case studies. Reducing solar loads and air leakage were also important factors for most case studies. However, even in urban case studies external and internal noise did not appear to influence the building and ventilation designs. Avoiding rain ingress was however, relatively important in many locations.

Table 5: Design Influence Level Matrix of different parameters on the selection of VC components and solutions (R denotes Rural; U denotes Urban; *denotes residential)

Country	Building	Surroundings	Lower Initial Costs	Lower Maintenance Costs	Lower Energy Costs	Reducing Solar Loads	Reducing Internal Loads	Reducing External Noise	High Internal Noise propagation	Elevated Air Pollution	Avoiding Rain Ingress	Insect Prevention	Burglary Prevention	Reduced Privacy	Air Leakage
IE	zero2020	R	H	M	H	H	L	L	L	L	M	L	H	M	M
NO.1	Brunla School	R	H	H	H	L	M	L	L	H	M	L	L	L	H
NO.2	Solstadbarnehage	R	L	L	H	L	L	L	M	H	L	L	L	L	H
CN	Wanguo MOMA*	U	H	M	H	H	L	L	L	L	M	L	M	L	H
AT.1	UNI Innsbruck	U	H	H	H	M	L	M	L	L	M	L	L	L	H
AT.2	wkSimonsfeld	R	H	H	H	M	L	L	L	L	L	L	L	L	M
BE.1	Renson	R	L	M	L	H	H	H	L	L	L	L	L	L	L
BE.2	KU Leuven Ghent	U	H	L	H	H	H	L	L	L	M	L	L	L	H
FR	MAL*	U	M	M	L	H	M	L	L	H	L	L	M	L	M
IT	Mascalucia ZEB*	R	H	M	H	H	L	L	L	L	L	L	M	L	M
JP.1	Nexus Hayama	R	M	M	H	H	L	L	L	L	M	H	H	M	M
PT	CML Kindergarden	U	H	L	L	M	M	L	L	L	M	M	M	M	L
JP.2	GFO	U	H	M	L	L	L	L	L	L	L	L	L	L	L
UK	Bristol University	R	H	H	H	L	H	L	M	L	M	M	H	L	L
NO.3	Living Lab*	U	L	L	H	H	M	L	M	L	H	L	L	L	H

Finally, reducing internal loads was important in about half of the case designs. It is difficult to draw global conclusions from the matrix in Table 5 but lower energy and lower initial costs along with reducing internal gains and lower solar loads are key factors when considering possible design solutions.

2.1. Morphology

Some of the case studies are small, dedicated research spaces or studies using small isolated parts of a building such as the lecture rooms in KU Leuven, Bristol University computer room and the zero2020 testbed in Ireland. Others are grand in scale such as the GFO building or Nexus Hayama buildings in Japan and The University of Innsbruck. In almost all cases, except arguably the Chinese case study in Changsha, the buildings can be classified as low rise with typically 2-4 floors. The average floor area for the buildings is 2,468m^2. However, when we remove Nexus Hayama in Japan (the largest case study at 12,836m^2) and University of Innsbruck this average reduces to 765m^2. At 400,000 m2 the GFO building is an outlier and is not included in these average floor areas. The smallest case study is the 100m^2 Living Lab in Trondheim, a research test facility for residential dwellings in cold climates. The shape coefficient, a measure of the building's shape and the efficiency of external building surface to floor area, for all cases, is shown in Figure 1. We can see that the small Italian zero energy home has a disproportionately high shape coefficient compared with the other values. Excluding this we have a minimum shape coefficient of 8.3 and a maximum shape coefficient of 96, still a good spread.

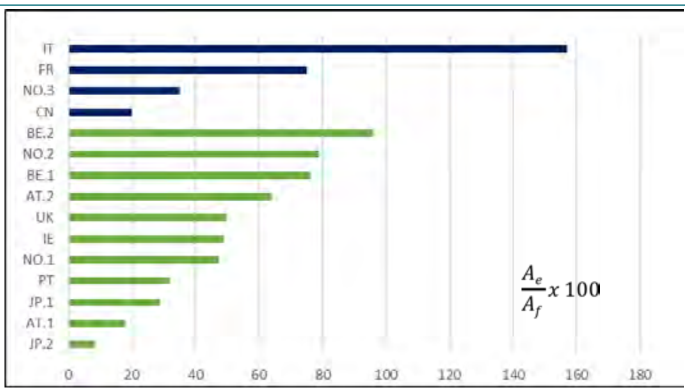

Figure 1: Building Shape Co-efficient for all Case Studies. (Residential shown in Blue)

Figure 2 shows the window to wall area ratios for each case study. Five of the case studies have relatively high window to wall area ratios at or greater than 50% while the average is 37%.

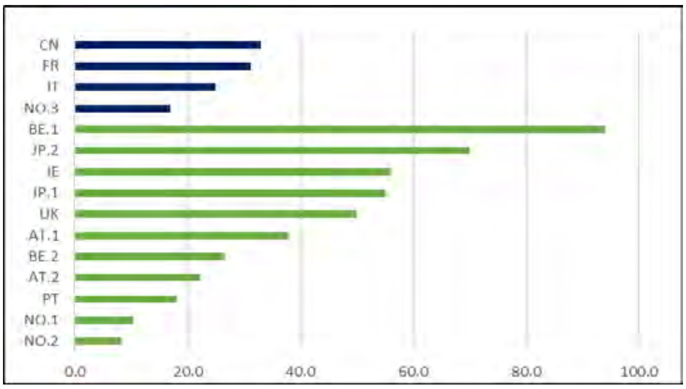

Figure 2: Window to Wall area ratio for all Case Studies. (Residential shown in Blue)

2.2. Thermal Properties

The case study buildings can generally be classified as high performance. Most buildings were designed as low energy or sustainable buildings. The average elemental wall U-value for all 15 case studies is 0.35 W/m^{2}K, which appears high but there is a large spread in individual values, with an average standard deviation across all elements of 0.27 W/m^{2}K. Some buildings such as the zero2020 testbed in Cork, have very high fabric performance (wall U-value of 0.09 W/m^{2}K) while other buildings, such as the Nexus Hayama (wall U-value of 0.86 W/m^{2}K), have lower performance, in part due to their respective national building regulations. This variation is in some way due to the different performance requirements and construction types for different climates. Six of the case studies can be classified as having heavy or very heavy thermal mass according to ISO13790:2008. Good air tightness is a recurring feature of most case studies with the average Air Change Rate (ACR) from infiltration at 1.13 h^{-1}, ranging from 0.51 to 1.85 h^{-1}, tested at a 50Pa envelope pressure differential.

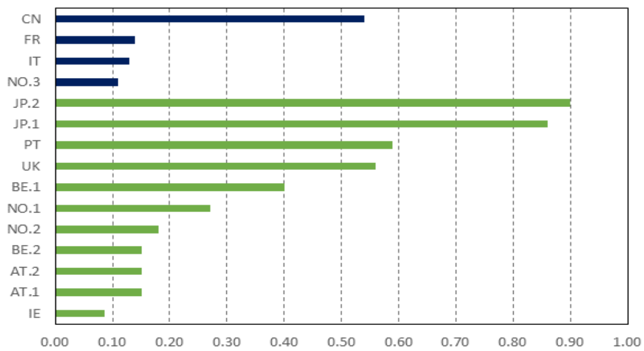

Figure 3: External Wall U-values for all Case Studies. (W/m^{2}K) (Residential shown in Blue)

3. VC strategies, components & control

3.1. Strategies & components

The case studies present a rich variety of VC solutions across a range of building types, morphologies and climates. Table 6 summarises VC concepts used in the case studies.

Table 6: VC Strategies in all Case Studies

		VC Strategies								
Country	**Building**	Natural driven	Mech. Supply Driven	Mech. exhaust driven	Natural night ventilation	Mech. night ventilation	Air conditioning	Indirect Evap. Cooling	Earth to Air Heat Exch.	Phase Chang eMaterials
IE	Zero2020	X			X					
NO.1	Brunla Primary school	X			X					
NO.2	Solstadbarnehage	X		X	X	X				
CN	Wanguo MOMA		X	X		X	X			
AT.1	UNI Innsbruck	X		X	X					
AT.2	WkSimonsfeld	X		X						
BE.1	Renson	X			X					
BE.2	KU Leuven Ghent	X		X				X		
FR	Maison Air et Lumiere	X								
IT	Mascalucia ZEB	X			X				X	
JP.1	Nexus Hayama	X					X			
JP.2	GFO Building	X				X	X			
PT	CML Kindergarden	X			X					
UK	Bristol University					X	X			X
NO.3	Living Lab	X								

The large majority, 86%, of the case studies use natural ventilation for VC strategies. The measured sensible internal loads for these case studies are all below 30 Wm^{-2} except for the Kindergarten in Portugal. The average is 25 Wm^{-2} (Different case studies include different types of equipment in this value so reference to the case study brochures is required for further details). All the climates were temperate. The number of days with the maximum daily external temperature greater than 25°C ranged from 0 to 123 days and the cooling season humidity is also low throughout except in Japan. Figure 4 highlights values for all case studies. The prevalent strategy was hybrid ventilation with 50% of buildings using this approach for VC. Many of these systems used mechanical exhaust ventilation when conditions required an increased airflow through the building.

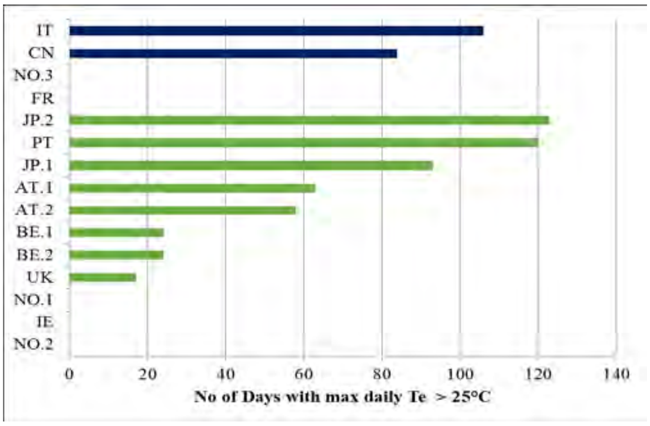

Figure 4: No of days with maximum daily external temperature above 25°C (Residential shown in Blue)

The sensible internal loads in these spaces were greater than 40 Wm^{-2} in Norway and Belgium, while in Austria and Italy they were less than 10 Wm^{-2}. Two out of the 15 case studies use mechanical ventilation as a VC strategy. A number of unique systems are employed in particular case studies such as, the integrated manual and automated slot louvres at zero2020 in Ireland (O'Donovan, O'Sullivan, and Murphy 2017; O'Sullivan and Kolokotroni 2014, 2016), the displacement ventilation system at CML Kindergarten in Portugal (Mateus et al. 2016); the earth to air heat exchanger at the ZEB Home in Italy (Causone et al. 2014) and the PCM mechanical ventilation system in the UK (Santos, Hopper, and Kolokotroni 2016).

3.2. VC system control

The control strategies used varied depending on the ventilation strategy of each case study building. Figure 5 conveys which parameters are used depending on the ventilation strategy as a percentage of all case studies. Thermal comfort was the main driver for controlling all ventilation systems. Temperature and relative humidity were the main parameters considered by control systems for comfort, while CO_2 was the main parameter considered when controlling for air quality. Internal air temperature was used by all cases studies with set-point control, while just one case study had a purely manual system. In addition, over 60% of case studies used an external temperature as part of their control strategy; this was typically a low temperature limit when the outside air was below the zone internal air temperature. Another point to note is the fact that exclusively mechanical systems did not consider precipitation or wind, while natural and hybrid systems did not incorporate external relative humidity levels into their control strategies but some included precipitation and wind.

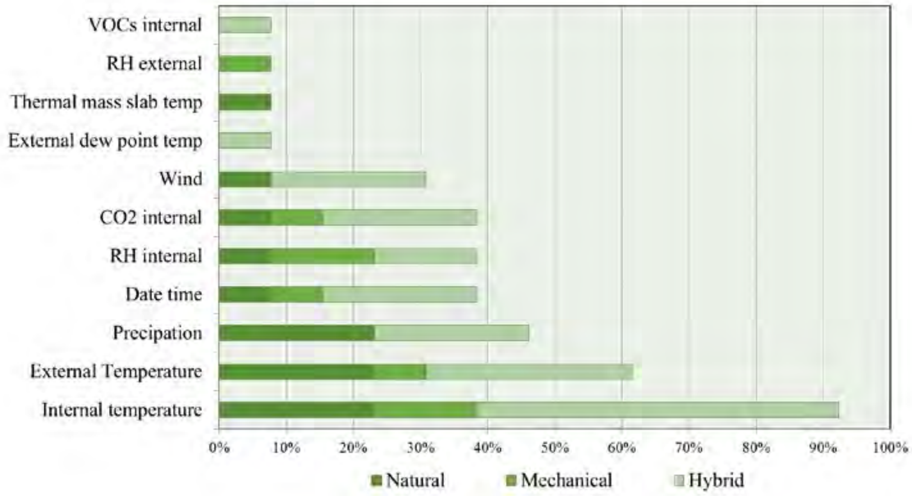

Figure 5: Summary of parameters used in VC control strategies for all case studies

Most control strategies for occupied periods used the internal zone temperature and an external temperature low limit as controlling parameters in ventilation strategies. There was no major correlation between the set-point used and the climate. The overall range of set-point temperatures were observed to be between 20-24°C where the mean internal air temperature set-point was around 22°C. The range of low temperature limits for outside air was between 10-18°C, with a mean external low temperature limit set-point of around 14°C. Around 54% of the case study buildings had a manual override switch or allowed occupant controlled ventilation during occupied hours as part of their typical occupied control strategies. All natural ventilation case studies allowed a form of occupant interaction with the ventilation system while 60% of hybrid systems allowed occupant interaction with the ventilation system. For systems that controlled depending on relative humidity an average set-point of 60% was observed. There were differing ranges of acceptability depending on whether the VC system was mechanical or natural. 69% of the case studies investigated incorporated a night ventilation strategy as well as an occupied ventilation control strategy. Typically, night ventilation strategies had different control parameters than ventilation strategies during occupied hours. The night ventilation strategies employed typically had a set-point for the zone as well as a limit on the properties of the air brought into the building also. The mechanical night ventilation strategies observed used only a combination of internal and external air temperature setpoints for control. The range of internal temperatures used for night ventilation strategies was between 15-23°C while the low limits on the external air temperature incoming in the building were between 10-18°C. Night ventilation was also dependent on the presence or absence of rain and wind speeds above a certain value. Typically, the wind speed had to be below 14m/s or 10m/s respectively and with no rain for night ventilation systems to operate. In cases where relative humidity was the control parameter, night ventilation would not be activated unless the relative humidity was below 70% for a given zone. Parameters specifically related to indoor air quality were not considered in any of the night ventilation strategies.

4. Sizing and simulation of VC

4.1. Sizing of VC systems

Information on the recommended aperture area when sizing VC systems is critical for the building designer. For almost all case studies, natural ventilation was adopted as either the sole source of VC or as part of a wider strategy, with, for example, natural supply and mechanical exhaust. It is generally beneficial to identify possible dimensionless parameters that provide a characterization of the system, thus allowing for comparable investigations across multiple different systems. Owing to this and the inherent importance of the ventilation opening geometry for the delivered airflow rate, a parameter calculated as the percentage opening area to floor area ratio, or POF, was obtained for each case study. The opening area used is the maximum available geometric opening area and does not incorporate the flow effects of the opening. Figure 6 presents POF values for all cases where this was relevant.

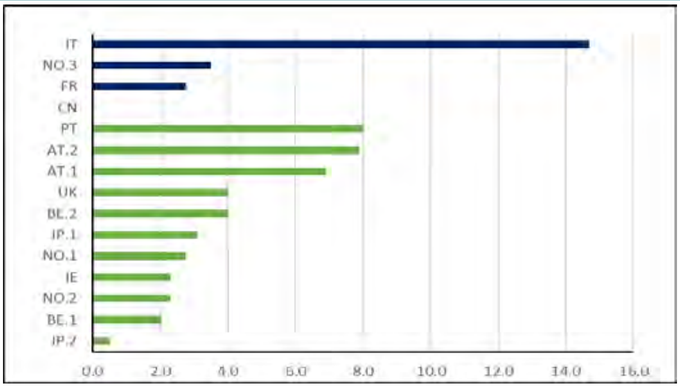

Figure 6: Percentage openable area to floor area for selected case studies. (Residential shown in blue)

We can see a large spread of values for the case studies. 65% of buildings had POF values less than 4%. There seems to be no correlation with building category. The two highest values are from Csa climates. Two of the lowest three values are from fully naturally ventilated offices. Natural ventilated buildings had a POF of 3.6% while hybrid buildings had a POF of 4.6%, or 6.0% when the Italian case study is included. Although several building regulations impose a minimum floor to opening area ratio of 5%, there is a generally accepted rule of thumb for designers when sizing openings at the concept stage of 1-3%. The lower end of this range appears inadequate when compared with these case studies. A range of 2-4% seems more reasonable.

4.2. Simulation of VC systems

Airflow performance and capacity sizing of the VC strategies and components, along with the building thermal performance, were investigated at various stages of the design using appropriate simulation tools. At the initial project scope development stages national standards and engineering guidance documents, such as those published by CIBSE in the UK, were used by some countries. Some countries begun to develop simplified energy models in different design packages such as PHPP and TAS while the Portugese case study used EnergyPlus from the initial stage right through to the operational performance evaluation stage. There was no single dominant tool for modelling VC across all case studies. For example, at the detailed design BSim was used for the naturally ventilated house in France, Windmaster and SIMIEN were used for all three cases in Norway, EnergyPlus was used in Portugal and in Italy. IES Apache was used in Ireland and the UK for detailed design but TRNSYS was adopted for the Irish case study for operational performance evaluations. Only in Japan was CFD used. IDA Ice was adopted in Norway for all operational performance evaluations.

5. Performance evaluation

All case studies completed operational performance evaluations specific to their building involving various experimental measurement campaigns. Each case study adopted different approaches and investigated different phenomena, examples of which include ventilation rate measurements, thermal comfort studies, analysis of internal thermal environments, investigation of the performance of specific solutions such as displacement ventilation, chimney-stacks, hybrid systems, cross flow ventilation, etc. It is not possible to present in this summary report the individual findings from these campaigns, however the reader is referred to the individual case study brochures for more information on individual findings.

IEA-EBC Annex 62 identified that, in order to assess the minimum performance of the VC strategy, one cooling season of internal air temperature data should be obtained. This data should then be compared with a previously defined overheating risk criterion based on two static thresholds. Table 7 presents a selection of results from the case studies. Overall, very good performance has been achieved by the VC solutions adopted in all case studies.

Table 7: Preliminary results of VC performance evaluation

Country	Building	Summer Design Day Values		overheating criteria / note	% Occ hrs above threshold		Occ hrs
		T_e	$T_{i,o}$		28°C	25°C	
IE	zero2020	26.0	25.0	T_i < 28°Cfor 99% occ hrs	0.7	5.5	2600
NO.1	BrunlaSchool	25.0	26.0	T_i > 26°C	0.0	0.0	2600
NO.2	Solstad	25.0	24.0	T_i > 26°C	0.0	0.0	2860
AT.1	UNI Innsbruck	34.0	27.0	T_i < 26 for 95% occ hrs	1.1	16.2	2600
AT.2	wkSimonsfeld	34.5	24.0	T_i > 26 zone / T > 29 gallery	0.0	5.0	3250
JP.1	Nexus Hayama	26.0	26.0	T_i < 28 for 99% occ hrs	1.0	40.0	8736
PT	Kindergarden	30.0	26.0	80% acceptability 99% hr occ	2.6	16.0	3640
UK	Bristol Uni	26.0	25.0	Adaptive TC Model	-	-	2600
BE.2	Renson Builing	-	-	Tz < 26°C for 95% of hocc Tz < 28°C for 99% of hocc	0.3	11.4	2600
BE.1	KU Leuven Ghent	-	25	T_i < 26°C for 95 % hr occ	0.3	5.1	1560
NO.3	Living Lab	25	26	T_i > 26	0.0	0.0	832

6. Lessons Learned

The case studies analysed in this project yielded over sixty four key lessons learned, the majority of which were considered important. Thirty one lessons emerged from the design and construction and 33 lessons were derived from case study buildings during operation and post occupancy. These are summarised separately.

6.1. Lessons from design and construction

Designing a building to incorporate VC can be challenging and may require a lot of detailed building information. While each challenge was different, the key lessons were as follows:
Most case studies analysed highlighted the need for reliable building simulations in the design phase of a VC system. This was considered most important when designing for hybrid ventilation strategies where multiple mechanical systems need harmonization. Some studies also revealed that simulating the window opening (occupant interaction as well as size) in detail was important.

- Customisation may be an important factor in designing a VC system. In order to ventilate certain buildings it may be necessary to design custom components. Some case studies highlighted the need to have custom design systems that were specific to national regulations and the use of a building or space. Some consideration should also be given to the client's expectations around specific issues like rain ingress, insect prevention, noise propagation, external noise and pollution.
- VC systems were considered cost-effective and energy efficient in design by most case studies, but particularly with naturally ventilated systems. It was indicated that designing to integrate manual operation and control was important, particularly in a domestic setting.

6.2. Operation and Post Occupancy

While systems may be designed to deliver high levels of comfort, IAQ and energy performance, achieving this in practice was difficult. All case studies emphasised that monitoring a building's post occupancy performance is important if not essential in building performance optimisation. Although some key lessons were more specific than others, the following general observations may be made:

- Engaging with the building owners or operators as soon as possible is integral to guaranteeing building performance for IAQ, comfort or energy savings. For some case studies this meant specifically educating or working with the facilities operator or manager for the building, for others it meant educating the building occupiers themselves.
- It was suggested by some that this engagement should occur already in the design stage.

- VC in operation is generally a good option. Case studies comment on the reduction of overheating and improvement of comfort conditions in the buildings that used outside air. However, correct maintenance and calibration of the systems is integral to maintaining performance.
- Some case studies highlighted the need to exploit the outside air more with lower external air control limits during typical and night-time operation. Others suggested that exploiting the thermal mass of a building was key. However, it was noted that care must be taken with considering these low temperatures as some case studies, particularly in cold climates, observed more incidences of overcooling than overheating.

Some additional specific lessons learned from particular case studies are summarised in Table 8 below. These are a sample from certain case studies. Each brochure includes lessons learned in a dedicated section at the end of the brochure.

Table 8: Examples of Specific Lessons Learned From Selected Case Studies

Country	Case Study	Specific Lessons Learned
JP.1	GFO Building	- Manual control is unsuitable for high-rise buildings because of the risk of falls. The NV opening should be controlled for each individual tenant to meet their own needs. - Automated control can reduce cooling loads, maintaining low velocities in the occupied zone. - NV opening can be controlled even in the time of disaster by emergency power supply.
JP.2	Nexus Hayama	- Regarding ventilation windows, it is important to install a screen door in the opening to prevent sound penetration and the invasion of insects. Securing a ventilation path (cooling & heating pit) that can be opened regardless of the outside conditions was also effective. However, consideration must be given to air quality and pressure loss.
PT.1	KML Kindergarten	- User training is essential and may need to be periodically renewed (every 3-4 years). In this school the current users were convinced that the chimneys were poorly designed skylights - Stack driven NV is very effective and self regulating and can meet the airflow rate goals in spring and winter
UK	Coolphase	- Reliable sizing tools are needed which consider both the use of the space (internal heat gains and variability) and external weather patterns
AT.1	Innusbruck	- A detailed evaluation of the building location, building structure and its operation profile during the concept phase was essential to adapt the ventilative cooling system to the building. - A data monitoring system is essential to optimize the building performance and interaction of different technical building systems. More than one cooling/heating period is needed to optimize systems.
IE	Zero2020	- Design simulations can easily over-estimate the ventilation rates for cooling. This must be considered in the design phase. Design should be conservative when estimating cooling potential.

7. Conclusions

During the past two decades, the use of VC has been slowly increasing. The best contemporary designs combine natural ventilation with conventional mechanical cooling. When properly designed, and implemented, these hybrid approaches maximize the VC potential while avoiding overheating during the warmer months. Yet, despite the potential shown in the case studies analysed in the guidebook, and other existing examples, the potential of VC cooling remains largely untapped. This study showed that a lot can be learned from collecting information about VC case studies that have demonstrated through measurement that they perform well and their internal environments are comfortable for an acceptable proportion of the occupied time. However, due to the heterogeneity of the cases analysed, it is difficult to draw general conclusions regarding recommendations for designers. The characteristics of each case study appeared unique due to the need for the approach to respond to a specific climate, the particular building usage, morphology and client criteria. Hybrid systems are the most common type of system for VC and the use of mechanical fans to complement a passive system should be strongly considered where possible. A combination of automated and manual control seemed to be the most adaptable and reliable solution to providing a system that worked well, with its users satisfied with its operation. The use of simulation in the VC system design phase can reduce the uncertainties that are usually associated with natural ventilation systems. When excluding outliers, a POF value in the region of 2 – 8% was recorded and choosing a value towards the higher end of this range at the concept design stage may be appropriate.

8. References

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9. Case Study Brochures

01_IE_zero2020
Key Features & Climate

1.1 Introduction - Zero2020 Building Retrofit

In 2012 Cork Institute of Technology in Ireland (CIT) completed the construction phase of zero2020, a pilot project/research testbed for the low energy retrofit of their existing $29{,}000m^2$ teaching building originally constructed in 1974. The retrofit pilot project covered approximately 1.0% of the total building floor area and is shown in Figure 1. The ventilation solution for the retrofit involved a flush faced external louvre system, each section comprising 17 air inlet slots (two sections comprise each vertical louvre bank), with a porosity of 0.057%. Inside the slot louvre ventilation is supplied using dedicated insulated doors controlled either manually or automated based on conditions in the enclosed spaces. The installed anodized aluminum slot louvre has a 45% net free open area for airflow and each louvre bank, comprised of two sections, and has overall structural opening dimensions of 0.30m (w) x 1.60m (h) with a net opening area for each section of $0.102m^2$ (there were two louvre banks in the test space). The primary aim of the envelope upgrade is to extend the lifetime of the building and ensure low thermal energy demand and improved occupant comfort. As an example of a “living laboratory” the zero2020 building allows researchers the opportunity to develop and calibrate virtual laboratories to study; microgrid applications, thermal comfort, and demand side management.

Fig.1 ZERO2020 BUILDING RETROFIT TEST-BED IN CORK INSTITUTE OF TECHNOLOGY, IRELAND

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Cork, Ireland
Building Type	Office
Retrofit (Y/N)	Y
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Natural
Year of Completion	2012
Floor Area (m²)	222.5
Shape Coefficient (%)	49
Openable Area to Floor Area Ratio (%)	2.3
Window to Wall Ratio (%)	56
Sensible Internal Load (W/m²)	29
Climate Zone (KG) (words?)	(Cfb)
No. of Days with T_e max > 25	0
Cooling Season Humidity	Low
Heating Degree days (Kd)	639

1.2 Local Climate

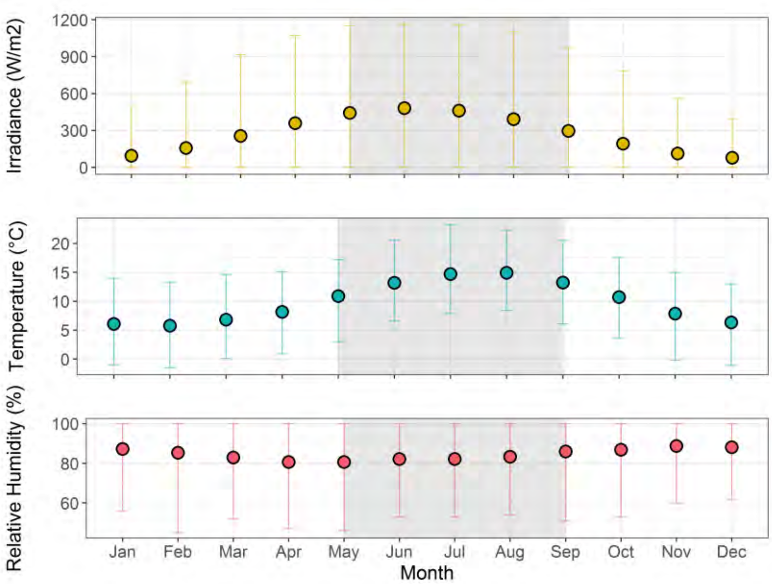


Fig.2 MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS IN CORK AIRPORT USING TMY3 FROM METEONORM 7 (COOLING SEASON SHOWN SHADED)

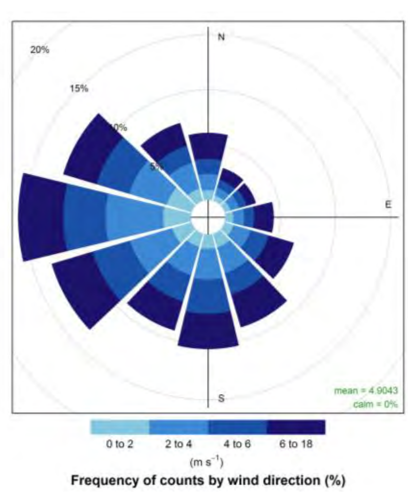


Fig.3 WIND ROSE FOR CORK AIRPORT (TMY3)

2. Building Information

2.1 Description

Due to the nature of retrofit in live buildings, solutions will have to be phased and as non- invasive as possible. A phased, modular, scalable, flexible, durable external retrofit with an intermediate internal retrofit is the most suitable design solution (coupled with a largely off-site build). The refurbished building, shown in Figure 4, which delivered a considerable reduction in energy consumption due to an energy efficient deep-retrofit solution, has functions as both a lecture room and office space is also the National Build Energy Retrofit Test-bed (NBERT) where data is gathered continually on internal and external conditions.

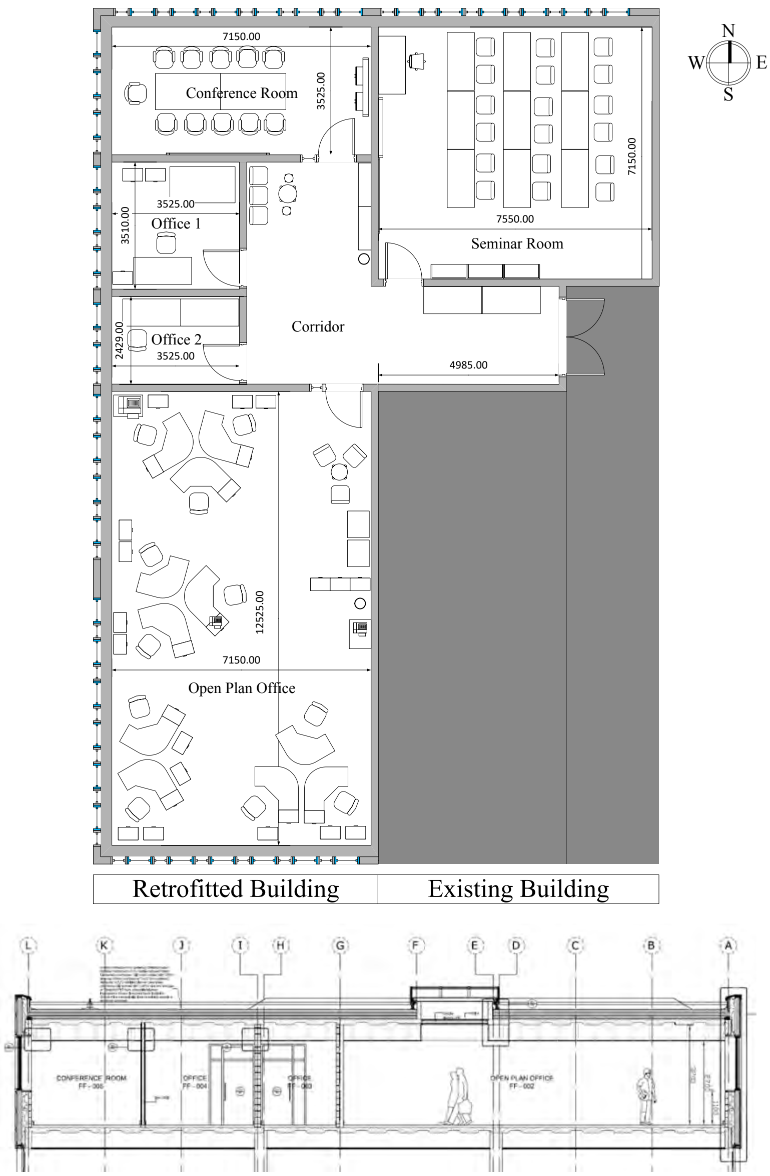


Fig 4. Top of image conveys floor plan of retrofitted building. Bottom of figure illustrates a section of the building.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	7
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	29
Window U-value	W/m^2K	1.09
Window g-value	(-)	0.517
Wall U-value	W/m^2K	0.086
Roof U-value	W/m^2K	0.092
Floor U-value	W/m^2K	0.783
Q-value (from Japan)	(W/ m^2)/K	0.075
Thermal Mass (ISO 13790)	-	Very Heavy
Window to Wall Ratio	%	66
Air-tightness (@50 Pa)	1/h	1.6
Shape Coefficient (1/m)	%	49

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	●
Energy costs	⬤
Solar Loads	⬤
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	•
Burglary prevention	⬤
Privacy	●
Air Leakage	●

3. Energy Systems

3.1 Heating System

The heating system comprises a Dimplex air-to-water heat pump with a maximum heating power output of 28kW at a COP of 3.6 (10°C ambient air temperature & 35°C supply water temperature). This is located at roof level, Figure 5, which supplies low surface temperature radiators distributed throughout the building at a water temperature of around 35°C. The system is controlled on a common return water temperature with localised occupant control at zone level achieved using thermostatic radiator valves. The system is also operated on a time scheduled basis with different schedules depending on the academic calendar. Figure 6 shows that annually the energy consumption due to heating is less than the PassivHaus criteria for specific heating demand of 15kWh/m^2/a.

Fig. 5 AIR SOURCE HEAT PUMP ON ROOF OF ZERO2020 BUILDING

3.2 Internal Gains (Lighting and General Services)

NBERT has about 2.8kW of installed lighting or around 12.5W/m^2 in the building is made up of mostly fluorescent T5 fittings. The small power appliances in the building are typical for that of a mixed use educational building. The small power equipment power density typically 22W/m^2. The percentage of consumption varies monthly, general services and lighting can account for over 70% of the energy consumption in most months. With greater than 75kWh/m^2/a attributed to electrical energy consumption improvements could be made.

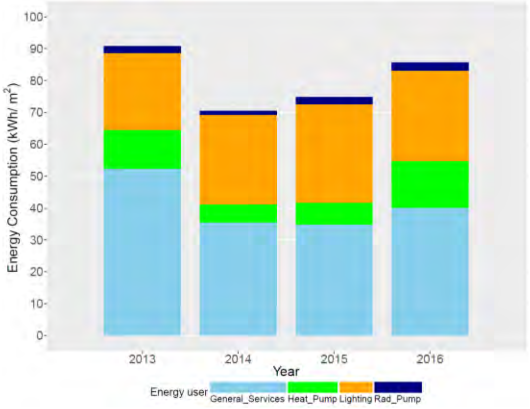


Fig. 6 OBSERVED ANNUAL ENERGY CONSUMPTION FOR NBERT BETWEEN 2013 AND 2016

3.3 Electrical Power Supply (PV, wind turbine & Microgrid)

The NBERT microgrid is a photovoltaic, wind turbine and battery integrated power system connected to the Zero2020 building. The virtual smart grid comprises the national grid, NBERT building, NBERT microgrid and the CIT main campus building. The microgrid powers the Zero2020 building while also exporting energy to the national grid. The microgrid consists of:

- 24kWp PV System (static). (see Figure 7)
- 0.5kWp PV System (dynamic tracking).
- 2.5kWp Wind Turbine.
- 1350Ah Lead Acid Battery.
- Grid tie inverter.

Fig. 7 INSTALLED PV ARRAY ON ROOF OF EXISTING BUILDING

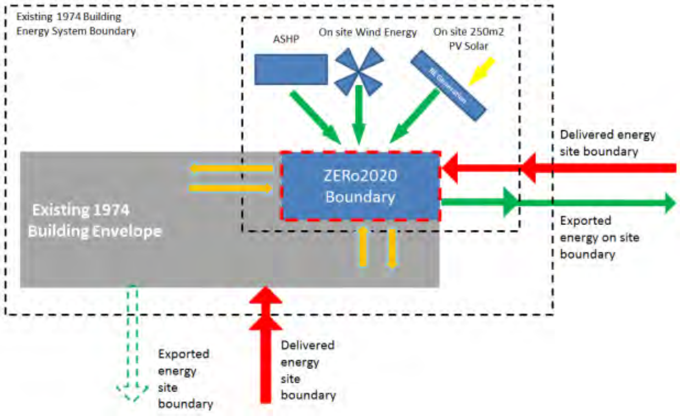


Fig.8 SCHEMATIC DESCRIPTION OF ZERO2020 TESTBED INFRASTRUCTURE

4. Ventilative Cooling

4.1 Principles

Single sided natural ventilation is the over-arching principle adopted due to the cellular nature of the existing internal layouts and constraints imposed regarding continued operation of the existing building. Large opening heights are employed to promote buoyancy forces in hot summer periods. Some instances of cross flow exist in the open plan office space when openings are activated on both south and west façades. Cooling is available during occupied hours through the activation of the openings. A combination of occupancy level manual openings and high level automated openings is available for increasing ventilative cooling (see Figure 8). Although there is reasonably consistent W-SW wind forces the system relies is predominantly buoyancy driven when operated in full height mode during the cooling season. A night cooling strategy is also available.

4.2 Components

The Multi Configuration Slotted Louvre (MCSL) ventilation solution for the retrofit consists of a flush faced external louvre system, (Figure 9). The insulated ventilation door is positioned inside of this louvre and is in the open position during operation. Each section comprises 17 air inlet slots with a porosity of 0.057%. The anodized aluminium slot louvre has a 47.5% net free open area for airflow and each louvre bank, comprised of two vertical louvre sections, has overall structural opening dimensions of 0.30m (w) x 1.60m (h) with a net opening area for each section of 0.102m². Table 4 contains component capacity dimensioning information. Figure 9 contain physical dimensioning data.

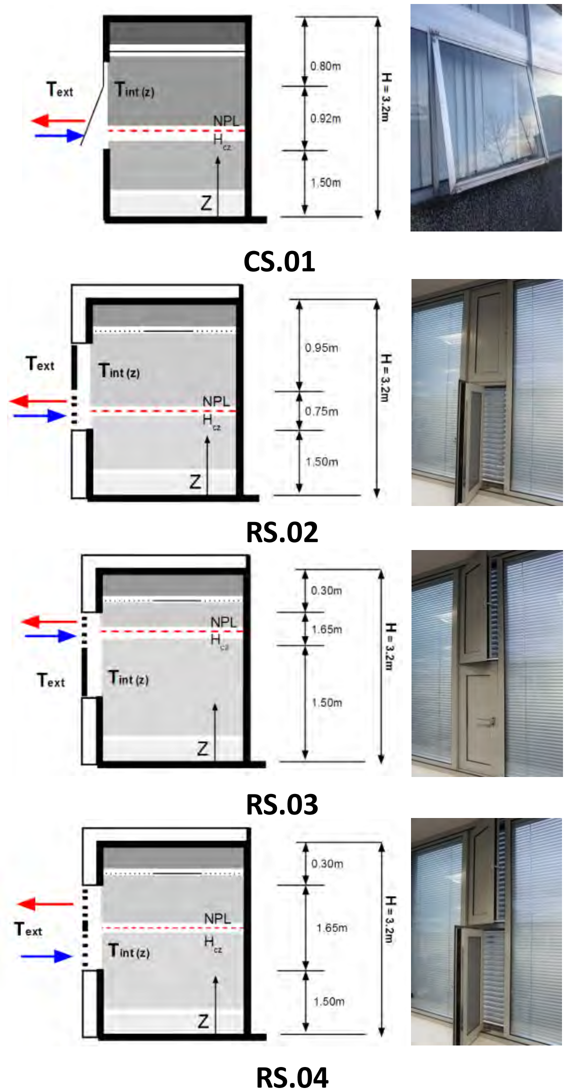


Fig. 9 SINGLE SIDED VENTILATION PRINCIPLE

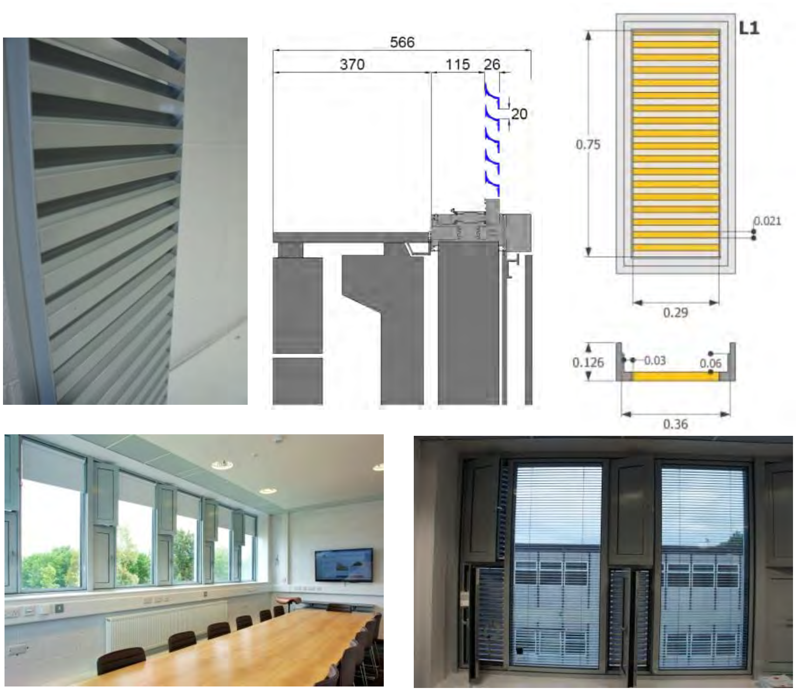


Fig. 10 SLOTTED LOUVRE VENTILATION COMPONENT

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area	0.102m²
Discharge Coefficient (Cd)	0.55 - 0.7
Overall Dimensions (1 louvre bank)	0.3m x 1.6m
Porosity (A_w/A_f)	0.057%
POF (Rs.02/3 / Rs.04)	2.1 / 3.6 %
Typical Q (RS.02/Rs.03/Rs.04) ACH	2/2/5

5. Control Strategy

5.1 Control Strategy Overview

The Control strategy for the ventilation system is largely based on the actuation of the high level automated insulated doors. The low level insulated ventilation doors are manually operated and there usage relies on the occupant perception of the internal environment. Figure 11 presents the control strategy flowchart. Table 5 below lists the controlling parameters.

Table. 5 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/Target	Value
Zone Temperature	Input	Variable
Zone Setpoint Temperature	Target	21°C
Night Cooling zone set point	Target	15°C
External Temperature	Input	Variable
External Temperature low limit	Target	10°C
Ventilation Door Position	Output	0% / 100%

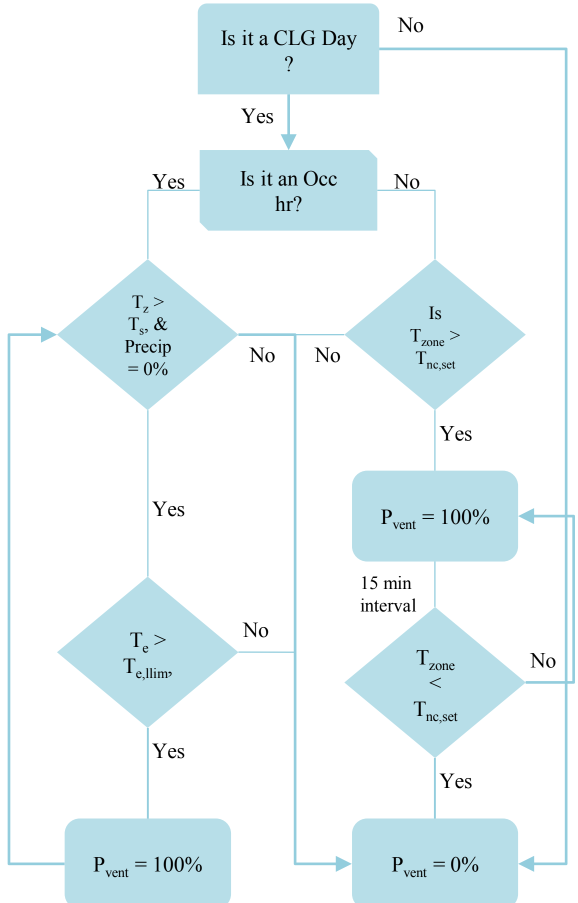


Fig. 11 AUTOMATED DOOR CONTROL FLOWCHART

5.2 Control Strategy Description

The high level automated ventilation louvres are activated based on internal zone temperatures. There are dedicated single zone temperature sensors for each room in building. When the following conditions are met then the high level insulated ventilation doors positions are driven to the fully open position. (The external louvres are permanently retained in place and have a static position):

- zone temperature above a certain value
- external temperatures above a certain value
- precipitation is below a certain value

Local override switches are available for manual control of the high level automated openings. These override switches control grouped banks of louvres as shown in Figure 12.

Fig. 12 AUTOMATED LOUVRE BANK CONTROL SECTIONS

6. Design Simulation

6.1 Summary

As part of the design scope various tools were at different stages to evaluate performance and assist in the specification of equipment and components. At detailed design stage a Whole Building Energy Simulation, (WBES), model was developed to investigate the risk of overheating for the building as well as specification of ventilation opening areas for each zone. The code and software was Apache/IES for thermal analysis and IES Macro Flo for airflow modelling. The simulation studies were conducted by Arup Engineers. Table 6 highlights what tools were utilised at each stage of the project while Table 7 summarises the target design performance criteria.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	Part L / CIBSE Guide A	Define Environmental Criteria
Concept Design	CIBSE Admittance	Initial Overheating Check
Detailed Design	IES Apache & Macro Flo	Thermal Analysis, Loads & ACR
Construction Design	Degree Day Study / PHPP	Energy Performance

6.2 Simulation of overheating risk

The simulated overheating risk indicated in Figure 14 using IES indicated that the highest level of overheating in the typical year would be in the in the seminar room. The total building level amount of hours greater than 25°C was calculated to be around 3% of the time annually. There were no hours in the typical year that was above 28°C.

6.3 Simulation of ACR

The simulated air changes rates indicated in Figure 15 in each zone due to infiltration was between 0.025 and 0.056. The highest simulated air change rates were seen in the Conference room which has the capability of using cross flow ventilation. Single sided office spaces like in Office 1 and Office 2 and the Seminar room the observed maximum air change rates were around 10.

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	26°C
T_z , Summer Operative Temp	25°C
Overheating criteria	T_z < 28°C for 99% hr_{occ}
Min IAQ air supply rate	10 ls^{-1} /pers
Cooling air supply rate	30 ls^{-1} /pers
Noise Level Rating (CIBSE)	NR30

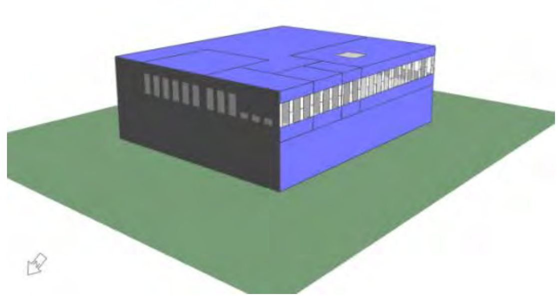


Fig. 13 DESIGN STAGE SIMULATION OF RETROFITTED BUILDING USING IES.

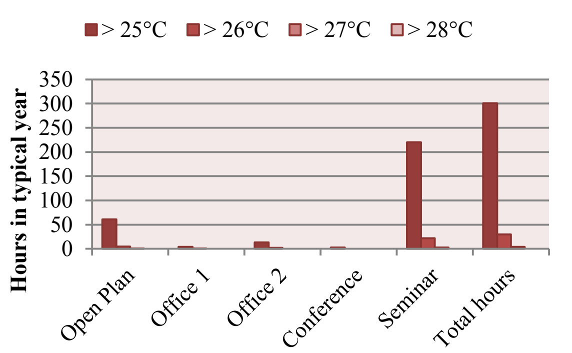


Fig. 14 DESIGN STAGE ESTIMATED HOURS OF OVERHEATING (AIR TEMPERATURE)

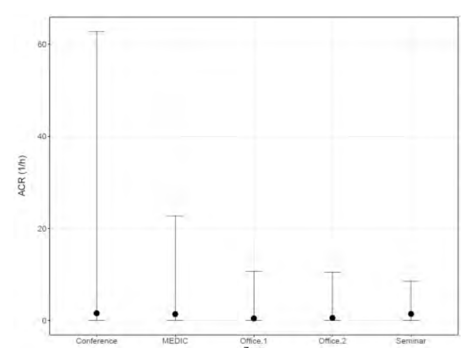


Fig. 15 ESTIMATED DESIGN STAGE AIR CHANGE RATES FOR EACH BUILDING ZONE

7. Performance Evaluation

7.1 Long-term performance evaluation

The cooling season occupancy levels in NBERT are in proportion to is small size. Following the academic calendar. During the cooling season (May to September) occupancy in the building is on average at 6 people during occupied hours (07:00 – 17:00). However, hours of occupancy can extend to the late evening towards the end of a typical week in cooling season. The building also has some typical weekend occupancy as a result of lectures.

NBERT operates typically in free running mode with infrequent use of its air source heat pump. By observing Figure 17 it can be seen that in Cork there is a lot of potential to naturally ventilate, with over 80% of the observed exponentially weighted external temperatures between 2013 and 2016 data between 5°C and 20°C. The general comfort performance of the building is good, when using the adaptive comfort standard EN 15251:2007, with 80-90% of occupied comfort recordings were in category III or higher. Generally, the percentage of occupied comfort recordings in category IV seldom exceeds 17%, as is shown in Figure 18. The majority of incidences in category IV were due to overcooling as opposed to overheating.

While annualised and average comfort conditions convey a situation where overcooling is more predominant, these averages are based on all zones. This could lead to some unoccupied zones skewing building level averages. If we take an isolated period in a cooling season in Figure 19 we can see that at room level overheating exists. However, when Table 8 is examined it seems that from a long-term perspective overheating is not an issue in the building.

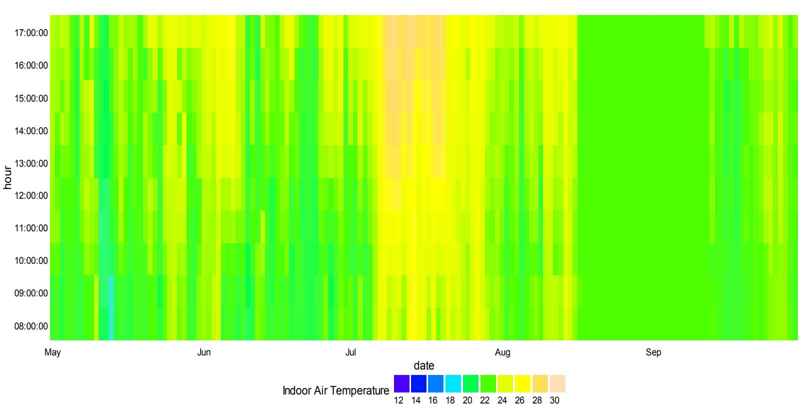


Fig. 19 Indoor air temperature heatmap Room B294 May – September 2013

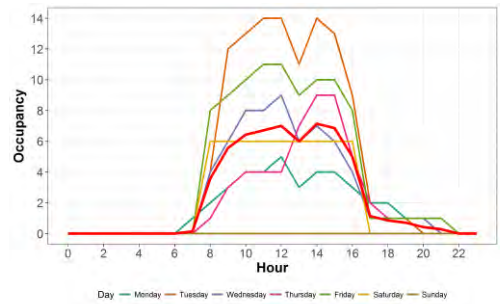


Fig. 16 Mean daily cooling season occupancy mean indicated in red

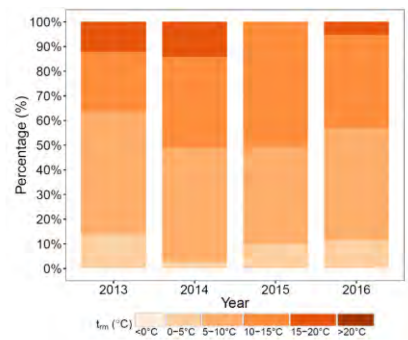


Fig.17 Percentage of exponentially weighted mean external temperatures for Cork Airport from 2013 to 2016

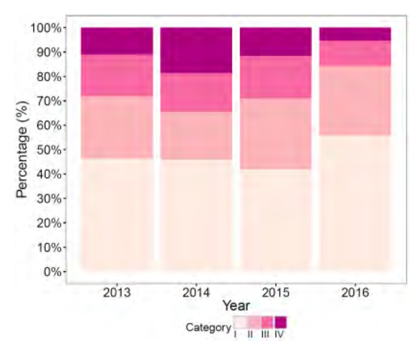


Fig.18 Long-term thermal comfort performance of NBERT

Table 8 Summary of CIBSE overheating criteria in NBERT during 2013

Room	CR1	CR2	CR3	h*
Seminar Room	0	0	0	0.0000
Conference Room	0.6	0	0	0.0050
Office 1	0.2	1	2	0.0020
Office 2	0	0	0	0.0006
Open Plan Office	1.05	0	0	0.9800

7.2 Ventilation Rates

Air Change rates (ACR) were measured at the building using a tracer gas concentration decay test method during two periods; July 2013 and August 2014. In July 2013 38 TGC decay tests were completed in total. Tests were completed in accordance with the procedures set out in ASTM E741-11. CO_2 concentration analysers were AlphaSense IRCA1 Non Dispersive Infra-Red (NDIR) Sensors. CO_2 sampling frequency was 0.1Hz. For further details see (O'Sullivan and Kolokotroni, 2014). Figure 20 presents distribution of ACR values obtained from measurements, while Table 9 presents summary performance data for eac MCSL configuration. In August 2014 measurements specifically investigated ACR through 1 low level louvre section with the insulated door removed in order to compare the performance of the louvre component with a simple opening aperture. 44 measurements were taken using a range of different opening dimensions. Table 10 presents efficiency coefficients for wind driven ventilation based on measured volumetric flowrates normalised using the free opening area and reference wind speed at 6.0m above roof level during measurements.

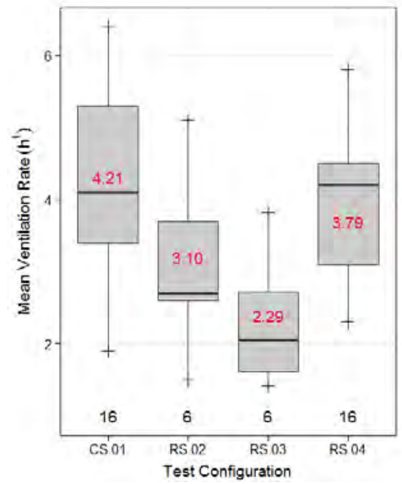


Fig. 20 ACR MEASURED IN RETROFIT AND EXISTING BUILDING DURING SUMMER 2013

Table 9 SUMMARY STATISTICS FOR ACR MEASUREMENTS OF MCSL SYSTEM

Config	Max ACR	Min ACR	SD ACR	Ave ACR	Wind Speed	Wind /Lee	Temp Diff
CS.01	6.4	1.9	1.5	4.2	1.4 – 5.2	9/4	4.2 – 8.9
RS.02	5.8	2.3	1.0	3.8	1.4 – 5.2	7/6	0.5 – 5.5
RS.03	5.1	1.5	1.3	3.1	3.3 – 4.2	4/2	1.1 – 5.3
RS.04	3.8	1.4	0.9	2.3	1.5 – 4.5	4/2	0.4 – 7.1

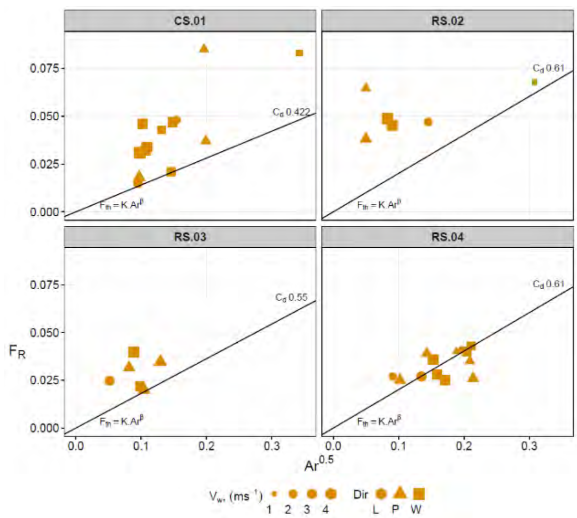


Fig. 21 ARCHIMEDES NUMBER VS FLOW NUMBER

7.3 ACR Driving Forces through the MCSL system

Different driving forces for airflow rates are present depending on which opening configuration is selected. The full height configuration RS.04 is buoyancy dominant while RS.02 is wind dominant. RS.03 is less well defined, likely due to its location relative to the room floor level. When openings are dominated by different driving forces this can have implications for correctly predicting the airflow rates and when a particular opening should be used as part of a control strategy.

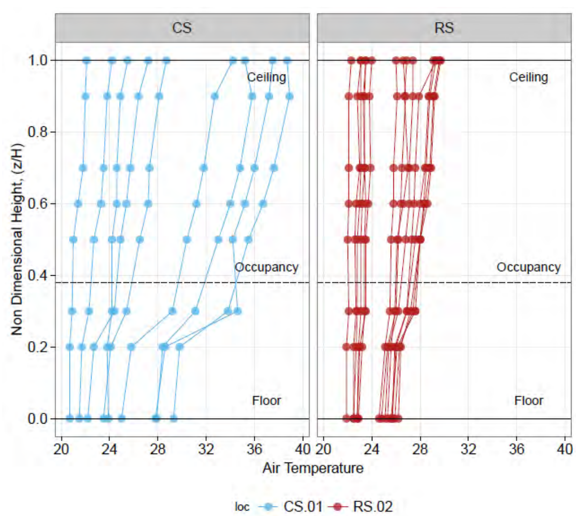


Fig. 22 STRATIFICATION IN EXISTING & RETROFIT BLDG

Table 10 NORMALISED VOLUMETRIC FLOWRATES

Type	All Wind Direction	Windward Direction	Leeward Direction
Slot Louvre	0.067	0.073	0.043
Plain Opening	0.039	0.040	0.036

7.4 Internal Thermal Stratification

The internal thermal stratification was measured during various ACR tests in 2013. All data was obtained during a particularly warm period with external temperatures reaching 10 year highs. Vertical temperature distribution under free cooling from outdoor air has been substantially modified following the retrofit works. In the retrofit space temperatures at the surface of the exposed roof slab are often 2-3°C higher than would be reported based on a mid-level zone thermostat which can be significant when designing systems for ventilate cooling of a low energy space.

7.5 Occupants thermal comfort for MCSL

The thermal comfort performance of the buildings slotted louvre ventilation system in response to overheating scenarios was assessed in a field study in May of 2015. In total the study evaluated the thermal perception of 35 participants a sample of participants are seen in Figure 23. The exponentially weighted mean external air temperature over the course of the study was 12°C. Four ventilation configurations, the buildings 3 main configurations were investigated with one extra control configuration (No Ventilation, RS-01). Subjectively, the configurations with smaller opening areas (RS-02 and RS-03) provided satisfactory levels of categorical comfort when compared to the standards utilised as in shown in Table 11. RS-02 and RS-03 did observe categorical differences in two of the three standards presented, which may suggest that a difference in comfort exists between openings of the same area but at different heights. The full height opening (RS-04) was seen to have the potential to overcool the control space, as a result of the high temperature differences observed between the internal and external environment during the study.

The results suggest that ASHRAE 55 predicts the categorical levels of discomfort accurately for overheating scenarios (RS-01) and for small louvre openings (RS-02 and RS-03). While EN 15251 and ISO 7730 underestimate the levels of discomfort experienced for all the configurations investigated. The failure for any standard investigated to predict the categorical levels of discomfort experienced in RS-04 could be due to the negative temperature ramps observed when using that configuration to resolve overheating as shown in Figure 24. However it is also possible that a negative subjective association may be present with larger openings in comparison to smaller openings aside from the negative temperature ramps observed, that may have led to the magnitude of the negative MTSV. Another possible reason for the difference between actual and predicted results could be due to the index or model used in predicting categorical comfort in all standards.

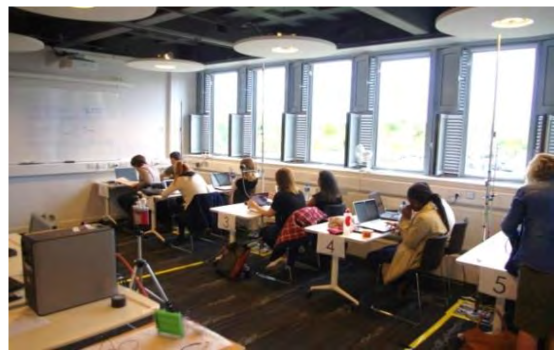


Fig. 23 IMAGE OF FIELD STUDY CONDUCTED ON THE 28-29TH OF MAY 2015

Table. 11 SUBJECTIVE PERFORMANCE OF EACH CONFIGURATION ASSESSED WITH RESPECT TO EXISTING STANDARDS

Config.	MTSV	ISO 7730	EN 15251	ASHRAE 55
RS-01	1.3	-	IV	Unacceptable
RS-02	-0.5	C	III	Acceptable
RS-03	-0.4	B	II	Acceptable
RS-04	-1.1	-	IV	Unacceptable

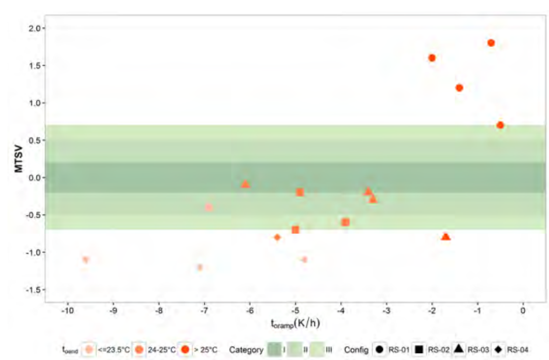


Fig. 24 SCATTERPLOT OF RELATIONSHIP BETWEEN MTSV AND OPERATIVE TEMPERATURE RAMP FROM THE START TO THE FINISH OF A TEST.

8. Lessons Learned

8.1 Summary

Key lessons learned during the project are summarised below. Overall communicating to the client and occupants how VC works and how it should be operated is key to successful implementation of the chosen strategy. The MCSL system has demonstrated good performance under a range of weather conditions and building usage. The system was a bespoke, factory built modular solution and its easily scalable nature means it has potential for use in other larger projects. The VC using single sided ventilation provided an acceptable internal thermal environment although instances of overcooling during shoulder seasons is possible and care must be taken when using automated control of openings during these periods. The solution is simple in its implementation and has proven to be effective with the combined manual and automated approach for the openings. The brochure contains summary information from over 4 years of research at NBERT relating to the VC solution. It is strongly recommended that the reader explore all publications listed in the references section 9.1 for a better understanding of the results and outcomes presented herein. The reader is also invited to explore further the data and the building at http://www.nbert.xyz.

8.2 Detailed list of lessons learned

Table. 12 Key Lessons Learned **Design and Construction**

Item	Lesson	Importance
1	The architectural input to the envelope design is a key factor when developing the VC strategy. The design requires close collaboration between engineers and architects to avoid poor performance or retrospective	H
2	Simulation of bespoke ventilation components can be difficult to undertake. Often designers will use standard approaches to investigate performance given their fee structure. Clients need to invest in proper assessment of bespoke solutions before proceeding with the construction	H
3	Commissioning of systems and performance evaluation for each season (soft landing) is critical	H
4	Confirmation from the client in writing that they understand and accept that free-running buildings have thermal comfort assessment based on not exceeding temperature thresholds for stated % hours as opposed to maintaining a set point continuously is important	M
5	Designers and contractors should be able to demonstrate delivering ventilative cooling designs based on post occupancy performance monitoring of buildings they have previously completed.	M

Table. 13 Key Lessons Learned **Operation / Post Occupancy**

Item	Lesson	Importance
1	Consideration should be given to the number of openings in each room. A high amount of openings may result in many not being activated by the occupants	M
2	Allowance should be made for fine tuning and tweaking of the control strategy for the VC system. It can take considerable time to establish an effective strategy with variable values and parameter settings	M
3	The effectiveness of occupant manually operated louvres to control ventilative cooling reduces over time (months). Occupants take less responsibility for maintaining indoor climatic conditions and engage less with the building use.	H
4	Data collection and internal environmental monitoring is only justified if there is a budget to: (a) to maintain the system (b) to analyse and report on the data collected	M

9. References & Key Contacts

9.1 References

O'Donovan, A., O'Sullivan, P.D., Murphy, M.D. A field study of thermal comfort performance for a slot louvre ventilation system in a low energy retrofit,. (2016) (under review)

O'Sullivan, P.D., Kolokotroni, M. (2016). A field study of wind driven flow through a slotted louvre ventilation system,. (2016) (under review)

O'Sullivan, P.D., Kolokotroni, M. Non-dimensional analysis and characterisation of driving forces for a single sided slot louver ventilation system, International Journal of Ventilation. (2016) 14:4 pages 335-348

O'Sullivan, P.D., Kolokotroni, M. Time-averaged single sided ventilation rates and thermal environment in cooling mode for a low energy retrofit envelope system. International Journal of Ventilation. (2014) 13:2 pages 153-168

O' Sullivan, P.D., Delaney, F., O' Riain, M., Clancy, T., O' Connell, J., Fallon, D., Design and Performance of and External Building Envelope Retrofit Solution for a Grid Optimised Concrete Structure: A Case Study, in: 30th Int. Manuf. Conf., (2013) pp. 1–12.

9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
Cork Institute of Technology	Client & Project Research Team	Paul O'Sullivan paul.osullivan@cit.ie +353 214312977
Henry J Lyons and Partners	Project Architect	Turlough Clancy Turlough.clancy@hjlyons.com +353214222002
Arup Engineers	Project Engineers	John Burgess John.burgess@arup.com +353214223200
ACE Controls	Building Management Systems	Noel Brennan Noel.brennan@acecontrol.ie +353214873005
AMS Ltd	Fenestration/Louvres/Ventilation Doors	Pat O'Hara pohara@ams.ie +353214705100
Wesco Building Systems	External cladding system	Christy O'Sullivan info@wesco.ie +353238847416
Kingspan	External Insulated Panels	Tony Ryan Tony.ryan@kingspan.com +441352716100
Summerhill Construction	Main Construction Contractor	John O'Sullivan info@summerhillconstruction.ie +353217337078

1.1 Introduction

Brunla primary school was initially constructed in 1967. It is placed in Stavern, Norway. The whole complex is 5600m^2 and the retrofitted building is 2500m^2. It initially used exhaust ventilation with manual control of the fans and manual opening of dampers in every room. The main building consists in 2 floors with four classrooms per floor and about 250 pupils. There are three classes per educational level. In 2009 the facade was renewed with a ten centimetre layer of insulation and new windows that allowed for natural ventilation were installed. In 2012 the windows control was enhanced by WindowMaster allowing for hybrid ventilation.

Now the system works with mechanical ventilation and four out of the six windows of each room are motorized. The windows are controlled individually. The position of the window motors detects window opening and registers the opening degree. The rehabilitation had the goal to improve students working condition but did not have the goal to upgrade to the highest efficiency standard. All the renovations had to be done in summer holidays periods to avoid interrupting student life.

Fig.1 Main building Brunla primary school

Table.1 Key information about building

Location	Stavern , Norway
Building Type	School
Retrofit (Y/N)	Y
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Hybrid
Year of Completion	2011
Floor Area (m^2)	2500
Shape Coefficient (m2/m3)	0.474
Openable Area to Floor Area Ratio (%)	18%
Window to Wall Ratio (%)	10.4
Sensible Internal Load (W/m^2)	49
Climate Zone (KG)	Dfb
No. of Days with T_e max > 25	0
Cooling Season Humidity	100
Heating Degree days (Kd)	2890 (Tb=17)

1.2 Local Climate

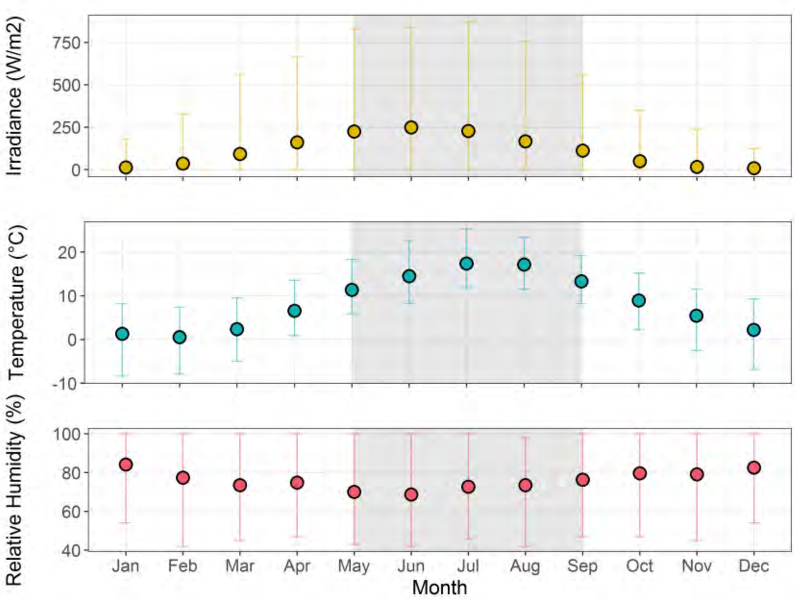


Fig.2 Mean, maximum and minimum external conditions in BRUNLA using TMY3 from Meteonorm 7 (cooling season shown shaded)

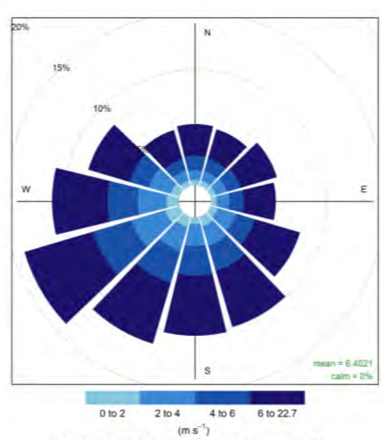


Fig.3 Wind rose for location provided

2. Building Information

2.1 Description

The building has a typical Norwegian outline and structure from the sixties. It is a squared two storeys building.
The windows ware renewed and now they are divided in a big window with an openable top hinged flap (in reality a narrow window) on the top. There are about 6 windows per classroom and 4 out of them are mechanically openable. The ventilation system was exhaust ventilation and all the supplied air is supplied due to negative pressure inside of the building.
Due to complains on low indoor air quality, renovations to improve it focused on:

- increasing insulation levels to reduce heating demands. The building was tighten and leakages rates were reduced, reducing draft risk.
- the ventilation system was improved to reduce complains due to headaches and allergies.

On the ground floor most of the classrooms are placed on the East side whereas in the second floor there are classrooms in both sides.

Fig 2. a) Top hinged window, b) weather station

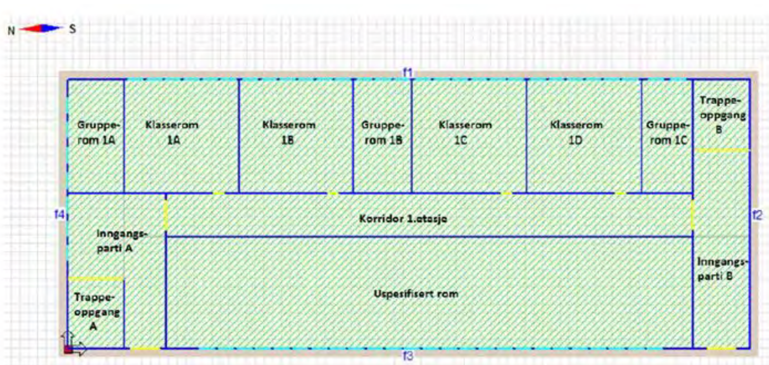


Fig 3. Floor plan of the first floor.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	10
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	49
Window U-value	W/m^2K	1.0
Window g-value	(-)	0.68
Wall U-value	W/m^2K	0.27
Roof U-value	W/m^2K	0.6
Floor U-value	W/m^2K	0.7
Thermal Mass (ISO 13790)	-	Moderate
Window to Wall Ratio	%	49
Air-tightness (@50 Pa)	1/h	1.5
Shape Coefficient (1/m)	%	32

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	⬤
Energy costs	⬤
Solar Loads	•
Internal Loads	●
External Noise	•
Internal Noise Propagation	•
Air Pollution	⬤
Rain Ingress	●
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	⬤

3. Energy Systems

The energy system of Brunla has not been improved during the renovation. Only some radiators have been changed when the insulation was increased and the windows were changed.

3.1 Heating System

The heating supply system to Brunla is done by hydronic system with low temperature radiators in the classrooms. Radiator's power output is controlled based on room temperatures and window opening. The radiators' supply is controlled individually in every room. When the windows are open, the radiator would reduce the water flow rate to reduce losses.

The school has its own pellets boiler, mounted in 2008. This has installed power of 250 kW to heating water. In addition there is a electrical boiler of 225 kW used for coverage of peak load. In addition, an electrical boiler of 300 kW is the back up heater.

Fig. 4 PELLET BOILER

3.2 Electrical Power Supply (PV, wind turbine & Microgrid)

The building is connected to the Norwegian power grid. This building has no PV, wind turbine or renewable electricity generation. The Norwegian power production is mostly based on hydropower.

Fig. 5 PICTURE OF THE SCHOOL DURING FEBRUARY

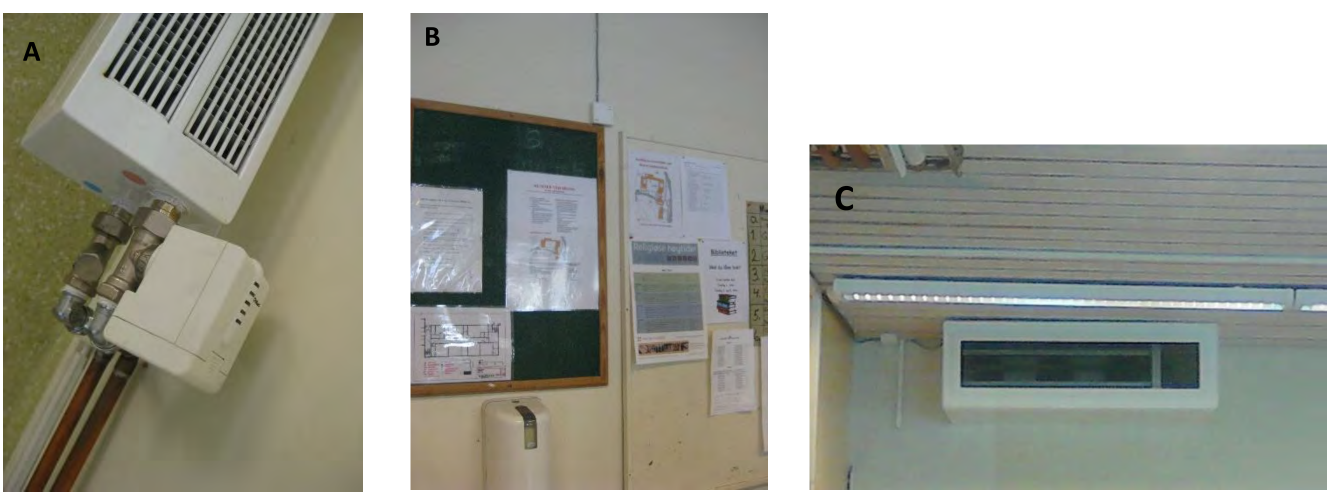


Fig.6 A) DETAIL OF THE CONTROLLER FOR THE RADIATOR, B) DETAIL OF THE PLACING OF THE TEMPERATURE AND CO_2 SENSOR C) EXTRACT OPENING FROM THE CLASSROOM

4. Ventilative Cooling

4.1 Principles

The ventilative cooling is provided by means of controlled windows opening. Each room has about 6 windows of which 4 have top hinged windows (works as a flap). The WindowMaster control system is responsible for their opening. Window opening can be combined in a hybrid mode with the exhaust ventilation. The ventilation when run naturally is single sided, however in periods with high CO_2 concentrations the exhaust fan is run enhancing a cross flow ventilation. If outdoor temperatures are too low, the rooms will only be ventilated with exhaust mechanical ventilation. A combination of automated window opening and exhaust ventilation is normally run as pulse ventilation and full opening during breaks.
Cooling is normally available during occupied hours due to low outdoor temperatures, however the risk of the window opening lies in overcooling and draft. In addition, users have the possibility to overrun the automatic control to open windows when wanted. In such cases, the system will return to automatic control after 15 minutes.

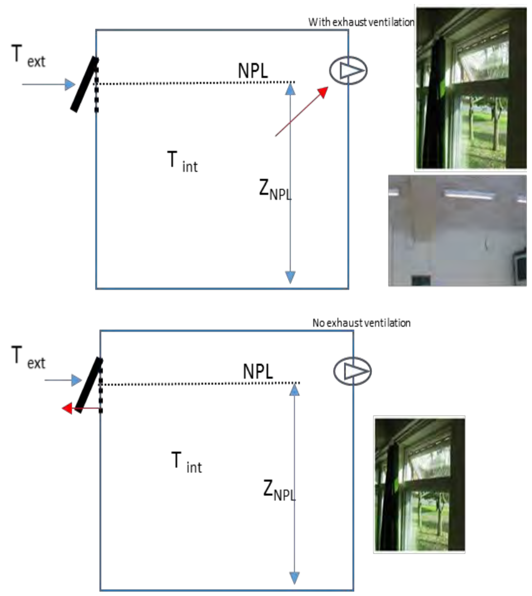


Fig.7 VENTILATIVE COOLING PRINCIPLE FOR HYBRID AND NATURAL VENTILATION

4.2 Components

The ventilation solution for the retrofit consists of four flaps over the windows that are automatically controlled per classroom. The windows can be opened up to 100 % (0.30 m^2 opening) in summer time and up to 50 % (0.17 m^2 opening) during winter times. When the window is opened under winter conditions, the radiators are regulated to reduce heat losses. When running the hybrid ventilation, window opening and ventilation dampers are interlocked.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Flaps
Free opening area	0.3 m^2
Discharge Coefficient (Cd)	0.64
Overall Dimensions (1 louvre bank)	0.46m^2/flap
Porosity (A_w/A_f)	0.19

Fig. 8 DETAILS OF DAMPER AND WINDOW OPENING DURING OPERATION

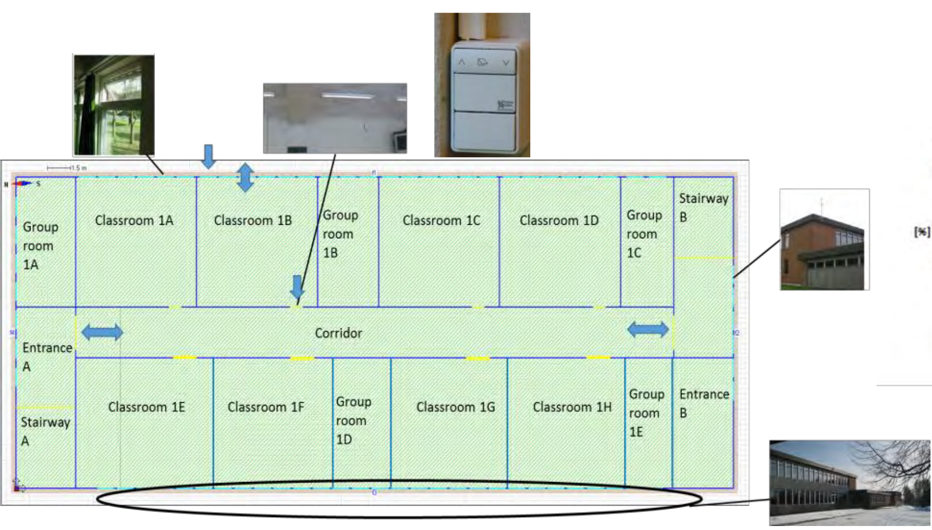


Fig. 9 HYBRID AND NATURAL VENTILATION AT BRUNLA. MOTOR CONTROLLED WINDOW AND EXHAUST TO A COMMON CORRIDOR

5. Control Strategy

5.1 Control Strategy Overview

The ventilation flow rate is controlled by the desired indoor air quality and temperature. During winter periods, the control of the temperature is the main focus and keeping CO_2 levels low is the second priority. During warmer summer conditions, control of the temperature has the highest focus. The windows open and close automatically on the basis of users wish for room temperature and the set CO_2 levels. Data from an outdoor weather station are also considered by the control system. The station is located on the roof and detects the outdoor temperature, rain, wind speed and direction.
Summer ventilation principle is mostly natural or hybrid, whereas in winter the ventilation is mostly mechanical exhaust ventilation.

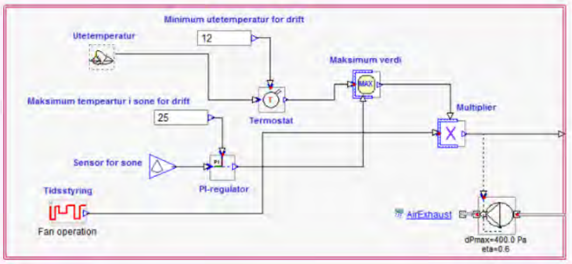


Fig. 10 EXHAUST VENTILATION CONTROL

Table. 5 CONTROL STRATEGY MODES

Parameter	Ventilation modus
Fresh air, standby when $T_{outdoor}$>20 °C	Natural ventilation
Comfort ventilation 12<$T_{outdoor}$<20 °C	Hybrid or natural ventilation
Just manual control. Any time the system can be overruled	Manual control
Closed windows. Comfort $T_{outdoor}$<12°C	Exhaust ventilation
Closed windows, night $T_{outdoor}$<12°C	Exhaust ventilation
Night ventilation T_{in}>20°C	Hybrid or natural ventilation
Pulse ventilation $T_{outdoor}$<12°C	Hybrid or natural ventilation
Slot ventilation $T_{outdoor}$<12°C	Hybrid or natural ventilation

5.2 Control Strategy Description

Setting the desired room temperature and CO_2 levels occurs individually for each zone. Users have the capability to overrun the control system, however, after 15 minutes, the system regains control and closes or open windows to achieve energy consumption reduction without worsening the indoor climate. The system control in winter, in cold periods windows are not so often opened and higher CO_2 concentrations, over 1000ppm, are allowed. Users can at any time open and close windows by using the override buttons.

Brunla's classrooms have two exhaust outlets on the opposite wall of windows. The outlets are connected to a duct with dampers, located above the ceiling in the corridor. During periods where natural forces are insufficient or in periods of high loads, pressure differences are increased using two variable speed exhaust fans. The fan is started and the dampers to the corridor are opened if BMS records too high temperature or poor air quality. A pressure sensor in the duct controls VAV dampers in each room separately.

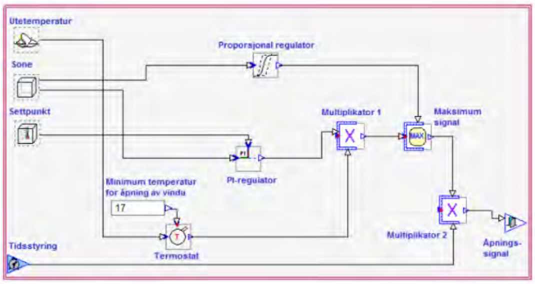


Fig. 11 WINDOWS CONTROL

6. Design Simulation

6.1 Summary

Previous to construction, Windows Master performed wind simulations in order to define the control parameters and strategy for windows opening. Simien was used for simulating the Energy demands and dimensioning of heating systems and ventilation. After construction validated simulations were performed in IDA ICE to analyse possible improvements. In addition, IDA ICE was used to simulate thermal comfort and energy consumption and modified/simplified windows control strategies.

Table. 6 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	25 ºC
T_z , Summer Operative Temp	26 ºC
Overheating criteria	T>26 ºC
Min IAQ air supply rate	0.5 ACH
Cooling air supply rate	-
Noise Level Rating	

Table. 7 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	NS 3700	Define environmental criteria/Energy use and IAQ
Concept Design	SIMIEN	Dimensioning of energy systems
Detailed Design	WindowMaster/ SIMIEN	Ventilation and window opening strategy. Overheating and overcooling risk analysis
Performance Analysis	IDA ICE	Thermal comfort and energy use

6.2 Simulation of overheating risk

Simulations show that if there was no cooling or temperature controlled ventilation, there would be risk for overheating in periods of high occupancy and solar thermal loads. Simulations also show that the use of window opening without further control would yield problems of discomfort related to over cooling and increased energy use. Simulations prove that a correct window control is enough to remove all cooling demands

Fig. 12 IMAGE OF IDA ICE MODEL

6.3 Simulation of ACR

The minimum ventilation when the building is not occupied is 0.5 ach. When the building is occupied the ventilation rates vary highly with a maximum of 4 ach

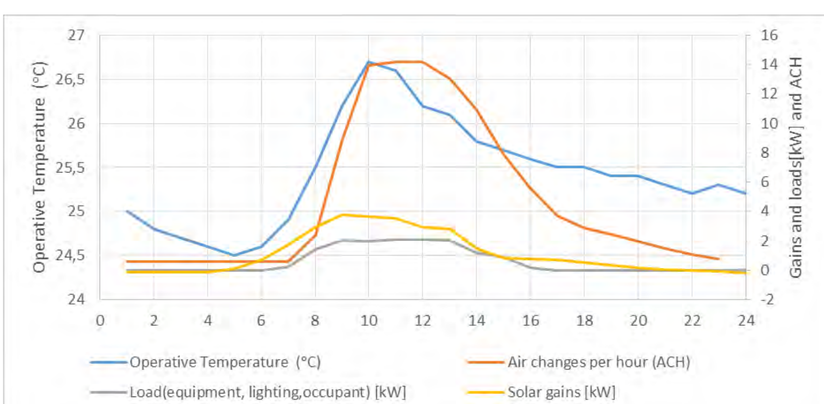


Fig. 13 RESULTS FROM THE WARMEST RECORDED DAY 22TH JULY IN CLASSROOM 1A

7. Performance Evaluation (200 words)

7.1 Measurement equipment

Brunla school is continuously monitored by BEMS. For the validation additional measurements were done. CO_2 was measured by KIMO AQ 200 and the equipment's uncertainty between 0 to 5000 ppm is ±50 ppm or 3% of the measured value. For temperature, Thermochron iButton were used and their uncertainty for measurements ranging -20 to 80° C, is ± 0.25 ° C or 3% of the measured value.

TSI Accubalance Air Capture Hood 8375 was used to measure air flow rates in the mechanical ventilation. Its uncertainty is ± 3% of measured value. For air velocities VelociCalc TSI 9555 was used and its uncertainty is ± 1.5% at 10 m/s. For the measurements of the linear opening of the windows a potentiometer connected to a Mitek was used.

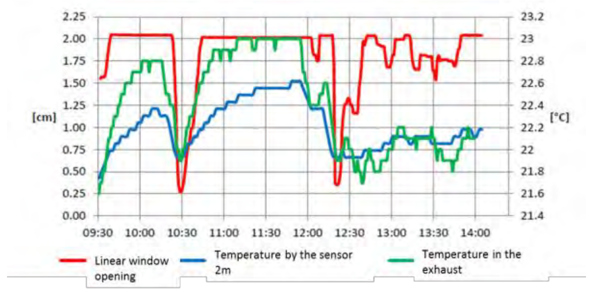


Fig. 14 TEMPERATURES VERSUS WINDOW OPENING

7.2 Internal Temperatures

The studied room is a classroom with high occupancy. It presents a large horizontal stratification. Next to the windows as a result of its opening, the lower temperatures are registered. Further inside (away from the window), high temperatures are measured, mostly when the exhaust ventilation is not run. In this case the control was far from the window and right below the window 17° C are measured. However, to avoid draft, it is a common practice to place the first table about half a meter away from the window.
During the periods with breaks, the students move around the classroom encouraging the mixing and reducing temperature differences.

Table 8 HOURS EXCEEDANCE

Parameter	Year 2013
Total Hours > 25°C	8
Occ Hours > 25°C	7
Total Hours > 28°C	4
Occ Hours > 28°C	3

Fig. 15 INSTALLATION OF MEASUREMENT EQUIPMENT

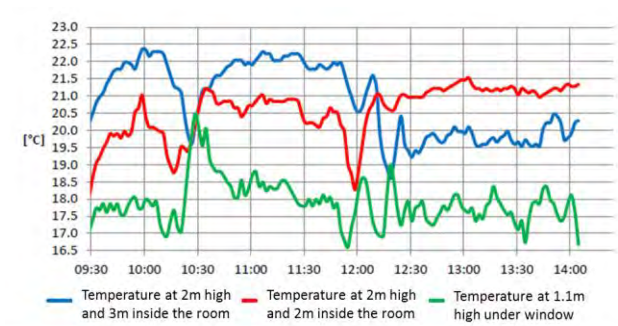


Fig. 16 INDOOR AIR TEMPERATURE FOR OUTDOORS TEMPERATURE OF 17 DEGREES AVERAGE

7.3 Occupancy Profiles

The occupancy level in the building is very much constant during school period. The kids arrive every day between 7:30 and 8 and are inside the room until 10:15 when they go out for a break of 15 minutes. Then they are at school from 10:30 to 12:00 when they go for eating lunch. Afterwards, they stay in the room till 14:00 when they mostly go home. Some students have homework extra hours for about one to one and a half hour. Then the school gets empty of pupils and only some teachers stay until 17:00. There would be a maximum of 24 pupils and 1 adult per classroom.

7.4 Performance simulations

The simulations performed in IDA ICE were compared to measurements in order to validate the model. The same model was used to compare energy use by different cooling strategies such as using mechanical cooling, no cooling at all and simplified controls.

Analysis of the energy consumption shows that the controlled window opening showed a decrease of energy consumption of approximately 5 % in comparison to conventional VAV, Table 9 shows the results. The main difference is in the HVAC auxiliary. The increase of energy consumption is natural as fan operation in the window controlled period is limited. The window controlled model has a larger heating demand, that makes sense because of periods of window operation even during the winter and shoulder season. When looking at the indoor climate, results from the synthetic summer climate simulation show that the hybrid ventilation solution provides a better comfort.
During simulations in synthetic winter climate, the indoor temperature stays in the region of the set point value for the heating system (20 °C) for all zones. There is however more temperature fluctuations for the hybrid case while windows are opened. Overcooling risk need to be a part of the hybrid control during winter and shoulder season. The simulations show fairly high CO_2-levels for all occupied zones, but they are all within the set point values. As expected, there is little to no window operation during winter.

Table. 9 ENERGY DEMANDS

	VAV and cooling Delivered energy [kWh/m²]	**Hybrid ventilation and VC** Delivered energy [kWh/m²]
Electric heating	66.8	78.9
Electric cooling	2.6	0
HVAC auxiliary	16.2	2.9

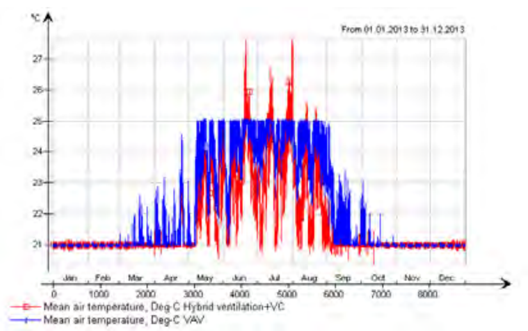


Fig. 17 TEMPERATURE DISTRIBUTION THROUGH THE YEAR

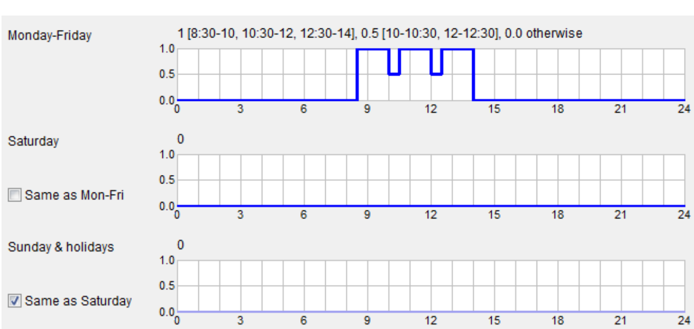


Fig. 18 TYPICAL HEATING AND COOLING SEASON OCCUPANCY PROFILES

8. Lessons Learned

8.1 Summary

In climates like the Norwegian the risk of over cooling due to prolonged times with window open has always to be evaluated. Studies of draft in order to control the risk of discomfort should always be considered when working with VC. The window opening and how it affects total use of energy has to be considered in detail.
Regarding the post occupancy period, it is important to say that this school was renovated with the goal of achieving a better thermal comfort and indoor air quality. High CO_2 concentrations and some hours of temperature above comfort level were measured, but in total, the IAQ is improved. Giving users the possibility to control and open windows has a positive effect on their perception of their indoor environment quality.

8.2 Detailed list of lessons learned

Table. 10 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	Importance to have reliable simulations of the draft	H
2	Being a renovation of a school better data from occupancy is available	H
3	The window opening strategy has to be simulated in detail	M
4	The profit of having a complicated system that has a higher investment costs should be better documented	L

Table. 11 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	Importance to have well calibrated sensors for control	L
2	Measurements show high concentrations of CO_2, it is difficult to ensure low energy use, good thermal comfort and low CO_2 at the same time	M
3	The risk of overheating and mostly overcooling has to be analysed on cold climates.	H
4	The users are specially satisfied of being able to control the system	H
5	The training of the janitor is very important for good performance of these advanced systems	M

9. References & Key Contacts

9.1 References

Algrøy , M. (2014) Energibruk og inneklima i skoler og barnehager med "mixed-mode" ventilasjon, Master thesis, NTNU.

9.1 Key Contacts

Table. 12 KEY PROJECT CONTACTS

Company	Role	Contact
NTNU	Project Research Team	Hans Martin Mathisen Hans.m.Mathisen@ntnu.no +4793059175
SINTEF Building and Infrastructure	Project Research Team	Maria Justo Alonso Maria.justo.Alonso@sintef.no +4794428591
Larvik Kommune	Project owner	Per Sortedal Per.Sortedal@larvik.kommune.no +47 33 17 16 78
WindowMaster	Ventilation control	Vidar Henning Hansen vidarhh@bsi-as.no +4791145777

03_NO.2_Solstad

1 Key Features & Climate

IEA EBC Annex 62
The IEA project on ventilative cooling

1.1 Introduction-Solstad kindergarten

Solstad Kindergarten is a low-energy, two storey building in operation since January 2011. It is located in Larvik, Norway, and it has a usable area of 788 m². It is one of several schools and kindergartens in the municipality of Larvik utilizing hybrid ventilation. Pushak was the architectural firm behind the kindergarten. Planning and design of the ventilation solution was done by Energetica Design, who served as HVAC consultants on the project. WindowMaster A/S was in charge of the HVAC system delivery.
The kindergarten has a hybrid mixed-mode ventilation combining motor controlled operable windows with balanced mechanical ventilation. In total, the building consist of 54 top hinged, operable windows, and five separate decentralized mechanical ventilation systems, each consisting of supply- and extract air terminals, ductwork and an air handling unit with exhaust air heat recovery and a heating coil. Mechanical cooling is not provided. The natural and mechanical ventilation systems cooperate in a mix between concurrent, changeover and zoned mixed-mode operation. The natural ventilation is performed as a combination of cross- and stack flow ventilation. There is a large common room called Agora in the center of the kindergarten, and all wings are connected to it through always open air hatches. As the Agora ceiling height is fairly large, air supplied to through controllable windows the wings will exit through controllable windows placed at the top of Agora.

Fig.1 SOLSTAD KINDERGARTEN IN LARVIK NORWAY

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Larvik, Norway
Building Type	Kindergarten
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Hybrid
Year of Completion	2011
Floor Area (m²)	788
Shape Coefficient (m²/m³)	0.7868
Openable Area to Floor Area Ratio (%)	22
Window to Wall Ratio (%)	8.2
Sensible Internal Load (W/m²)	40
Climate Zone (KG) (words?)	Dfb
No. of Days with T_e max > 25	0
Cooling Season Humidity	100
Heating Degree days (Kd) (for T_b = 19°C)	3870

1.2 Local Climate

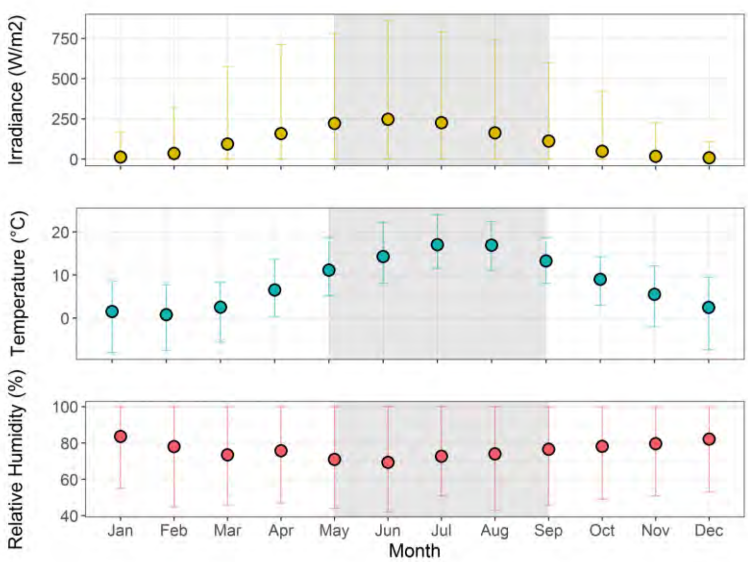


Fig.2 MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS IN LARVIK AIRPORT USING TMY3 FROM METEONORM 7 (COOLING SEASON SHOWN SHADED)

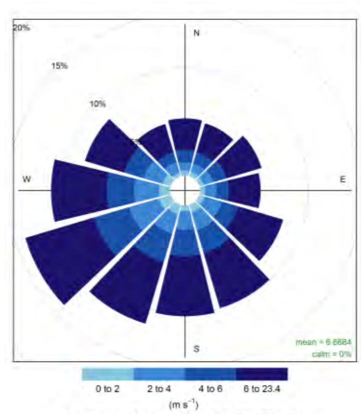


Fig.3 WIND ROSE FOR LARVIK AIRPORT

2. Building Information

2.1 Description

Solstad kindergarten is a low-energy, two storey building in operation since January 2011. It can roughly be divided in 4 one storey wings, each one with an age group. Each wing has one kitchen, one bathroom and one playing room. All the wings are connected to the common area called Agora. The ceiling height in the agora is higher than in the wings. The offices of the teachers and management are placed in the second floor. The area called winter garden is a room with glass walls where kids play during winter if it is too rainy.

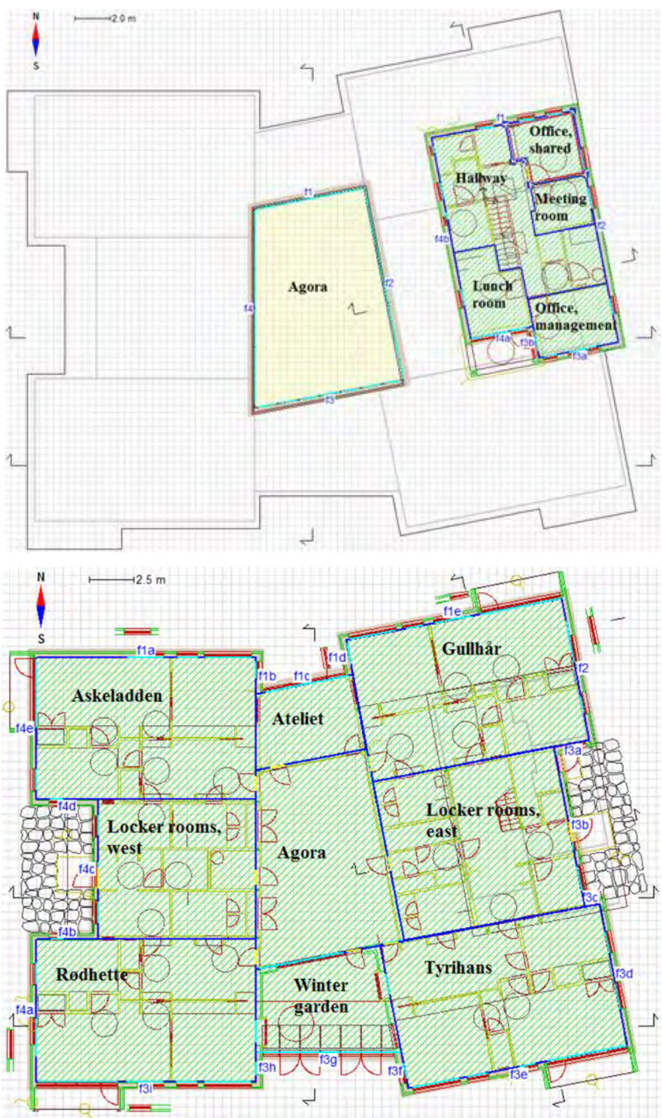


Fig 4. DRAWINGS OF GROUND AND FIRST FLOOR.

Table.2 BUILDING PROPERTIES

Property	Unit	Value
Occupant density	m^2/p	9
Hours of occupancy	h/week	55
Sensible Internal Load	(W/m^2)	40
Window U-value	W/m^2K	0.92
Window g-value	(-)	0.68
Wall U-value	W/m^2K	0.18
Roof U-value	W/m^2K	0.11
Floor U-value	W/m^2K	0.06
Thermal Mass (ISO 13790)	-	Light
Window to Wall Ratio	%	8.2
Air-tightness (@50 Pa)	1/h	1
Shape Coefficient (1/m)	%	0.7868

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	●
Energy costs	⬤
Solar Loads	●
Internal Loads	●
External Noise	●
Internal Noise Propagation	⬤
Air Pollution	⬤
Rain Ingress	●
Insect prevention	●
Burglary prevention	●
Privacy	●
Air Leakage	⬤

3. Energy Systems

Solstad Kindergarten is supplied with heat from a heat pump, an electric boiler, and electricity from the grid. The space heating is hydronic.

3.1 Heating System

The kindergarten has a hydronic floor heating distribution system with a ground source heat pump covering the base load, and an electric boiler covering the peak load. The heat pump efficiency is measured to 2.4 on a yearly average. The hydronic system temperatures are 45/35 °C. The system is designed so that the electric boiler covers 10 % of the heating demand and 50 % of the hot water demand (pre-heating). Heating is provided to the building 24 hours a day, 7 days a week. The building is supposed to use 46.4 kWh/m² for heating demands and 10 kWh/m² for domestic hot water needs.

3.2 Electrical Power Supply (PV, wind turbine & Microgrid)

The electrical power is supplied by the Norwegian power network based mostly on hydropower.
This building has no PV or wind turbine and is connected to the national grid.

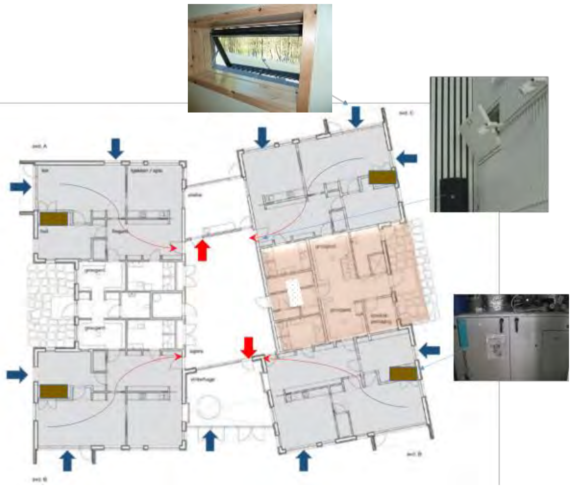


Fig. 5 Natural and mechanical ventilation at Solstad. Motor controlled window, hatches between wing and agora and mechanical ventilation

Fig. 6 North façade of building

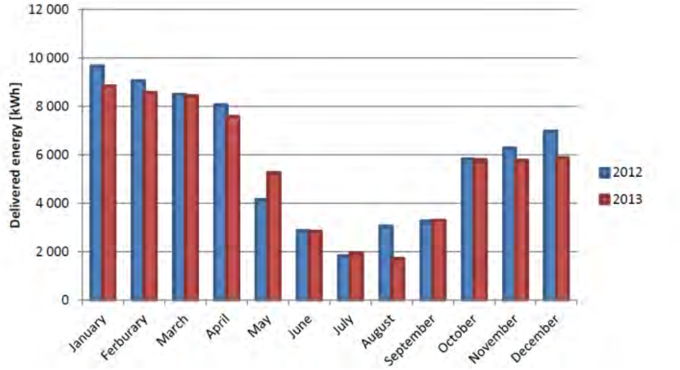


Fig.7 Monthly breakdown of delivered energy to Solstad kindergarten for 2012 and 2013. Logged by Energetica Design.

Fig. 8 Window opening towards Rødhete

Fig. 9 Detail heat pump

4. Ventilative Cooling

4.1 Principles The solution at Solstad can be defined as a mixed-mode system combining motor controlled windows with balanced mechanical ventilation. Mechanical cooling is in no form provided to the kindergarten. There are in total five separate mechanical ventilation systems at Solstad, each consisting of supply- and extraction air terminals, ductwork, and an air handling unit with exhaust air heat recovery and a heating coil. The mechanical system is highly demand controlled with the exception of bathrooms and locker rooms which is always provided with air extracts and over flow from other areas. The VAV operation of the mechanical systems is supported by speed control of the fans and pressure sensors in the ducts.
Natural ventilation is performed as a combination of cross- and stack ventilation. There is a large common room called Agora, in the center of the kindergarten, and air hatches connecting it to all the wings of the kindergarten. These hatches are normally open, but can be closed in case of fire. Agora has a fairly large ceiling height and motor controlled windows placed at the top of the walls. This way, air is supplied in the wings and exits through the windows of Agora.

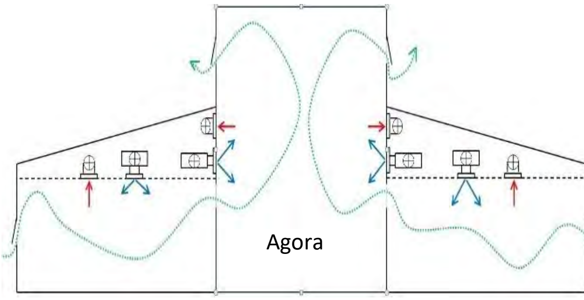


Fig.10 NATURAL AND MECHANICAL VENTILATION PRINCIPLE

4.2 Components

Figure 11 shows some of the 54 top hinged, operable windows. Every one of the four wings and the administration floor have a separate decentralized mechanical ventilation systems, each consisting of supply- and exhaust air terminals, ductwork and an air handling unit with exhaust air heat recovery and a heating coil.
Figure 12 shows a picture of the East façade and figure 10 shows the ventilation principle.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Flaps
Free opening area	0.1-0.4 m^2
Discharge Coefficient (Cd)	0.58-0.64
Overall Dimensions (1 louvre bank)	0.1-0.36-m^2/flap
Porosity (A_w/A_f)	0.17

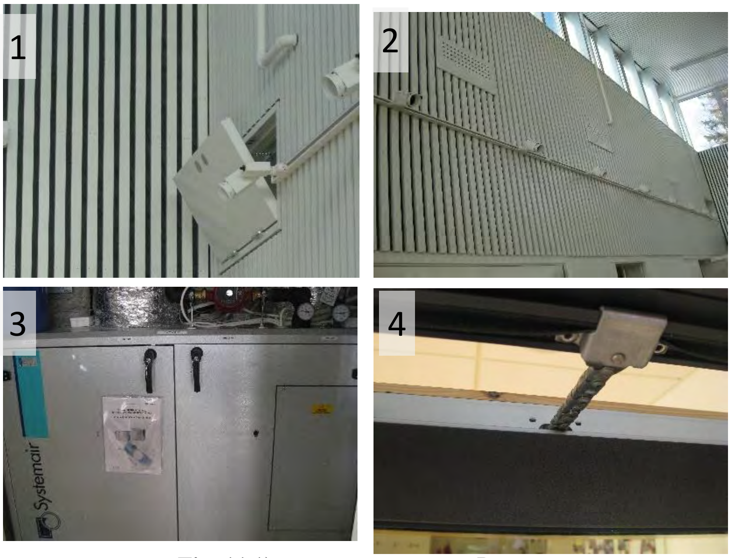


Fig. 11 1) HATCH SEPARATING RØDHETTE AND AGORA.2)WINDOWS IN THE AGORA + INLETS FOR MECHANICAL VENTILATION 3)AHU 4)WINDOW OPENING CHAIN

Fig. 12 EAST FAÇADE OF SOLSTAD KINDERGARTEN.

5. Control Strategy

5.1 Control Strategy Overview

The automated windows are operated provided either high CO_2 concentrations or high indoor temperatures. This means that indoor temperature is the defining measure on thermal comfort, and the level of CO_2 the defining measure regarding air quality. Mechanical system operation is connected to the window control in a changeover-, concurrent- and, to some degree, zoned mixed-mode system, entirely depending on the operation and control strategies.

Fig. 13 SOUTH AND NORTH FACADE

Table. 5 CONTROL STRATEGY IN SUMMER AND WINTER PERIODS

Winter operation	**Summer operation**
During winter, window operation is limited in order to prevent cold draught and large heating demands. Mechanical ventilation operates with a zone setpoint of 900 – 1200 ppm CO_2, whereas window operation has a CO_2-setpoint of 950 – 1500 ppm. Window operation is only allowed when the indoor temperature exceeds 19 °C, and is limited to 50 % of maximum opening. This setup entails that mechanical ventilation handles most of the ventilation needs as it has a stricter CO_2-setpoint than the windows. Window operation will only occur if the mechanical system is insufficient in controlling the CO_2 concentration in the zone.	During summer, the zone sepoint for window operation is an indoor temperature exceeding 21 °C. Mechanical ventilation operates with a CO_2-setpoint of 900 – 1300 ppm. Seeing that indoor temperatures will exceed 21 °C much of the summer season, mechanical ventilation is not utilized very often as air flow rates needed in order to remove surplus heat often are larger than air flow rates needed for CO_2 control. (4) Summer operations also allows night-time ventilation. If zone temperatures exceeds 23 °C after operating hours, the building will use window ventilation to cool down the zones to a minimum of 18 °C with a limitation in window opening of 50 %.

5.2 Control Strategy Description

During summer season, sustaining thermal comfort is the main priority. This normally entails that there is little to no mechanical ventilation, and if the indoor temperature in a zone exceeds that of a set value, the operable windows connected to that zone will start to open and provide cooling. If, however, this set value is never exceeded and CO_2-levels in the zone rise above a relatively high set limit, mechanical ventilation will start. Cooling by night-time window ventilation is also a possible feature when in summer operation. During winter season, achieving satisfying air quality is the main priority. Direct fresh air supply from the windows during the cold season places large demand on the heating system and drastically increases energy consumption. Therefore, during winter season, window operation is limited. The mechanical system is controlled by a CO_2 set value that is lower than the set point for window operation. Window operation will therefore only occur when the mechanical system is insufficient in decreasing the CO_2-levels and the indoor temperature is higher than a set value. Also, during the winter season, the maximum degree of window opening is restricted. The janitor is in charge to change the seasonal mode.

Wind speed, wind direction and precipitation also contribute to limit the maximum degree of window opening in order to prevent material damage and over-ventilation. Another aspect of the window operation is that the control schemes are designed to have short periods of fresh air supply on a time scheduled basis.

The system allows for user interaction and a large portion of all windows can be manually overridden by the occupants through switches placed in the zones. If manually overridden, it will stay at set position for 30 minutes before resuming automatic operation.

Table.6 DEGREE OF WINDOW OPENING VS WIND

With Rain		**Without rain**	
Wind below (m/s)	Maximum window opening degree (%)	Wind below (m/s)	Maximum window opening degree (%)
3	50	10	50
8	25	12	30
		14	10

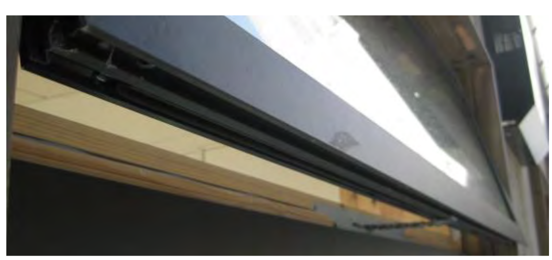


Fig. 14 WINDOW SEEN FROM OUTSIDE

6. Design Simulation

6.1 Summary

Previous to construction, Windows master performed wind simulations in order to define the control system and strategy for windows opening. Energy design was performed with Simien simulations for dimensioning of heating systems and ventilation. After construction validation simulations were performed in IDA ICE to analyse thermal comfort and energy consumption. As well simulation of modified windows control strategies were performed in IDA ICE.

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	25
T_z , Summer Operative Temp	24
Overheating criteria	T>26
Min IAQ air supply rate	$7 ls^{-1}$
Cooling air supply rate	No mechanical cooling
Noise Level Rating	

Table. 8 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	NS 3700	Define environmental criteria/Energy use and IAQ
Concept Design	SIMIEN	Dimensioning of energy systems
Detailed Design	WindowMaster/ SIMIEN	Ventilation and window opening strategy. Overheating and overcooling risk analysis
Performance Analysis	IDA Ice	Thermal comfort and energy use

Fig. 15 IMAGE OF IDA ICE MODEL

6.2 Simulation of overheating risk

Simulations show that if there was no cooling or temperature controlled ventilation, there would be risk for overheating. Simulations also show that the use of window opening without further control would yield over cooling and increase energy use.

6.3 Simulation of ACR

The minimum ventilation when the building is not occupied is 0.5 ach. When the building is occupied the ventilation rates vary highly from room to room as described by Øgård (2014).

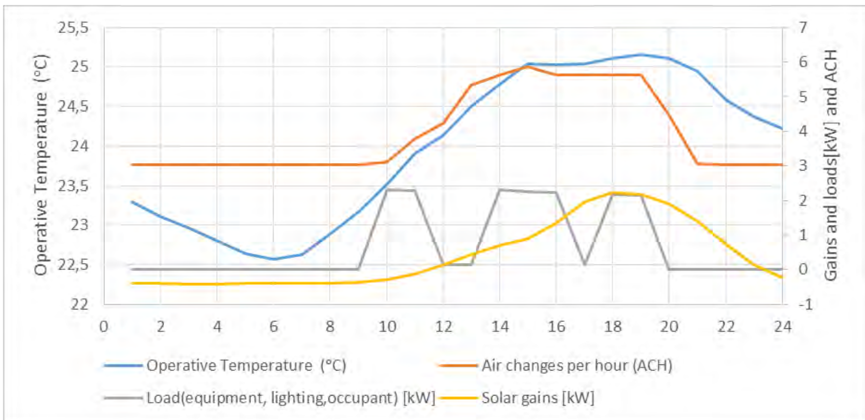


Fig. 16 RESULTS FROM DESIGN STAGE SIMULATIONS

7. Performance Evaluation

7.1 Measurement methods

The analysis of the performance of Solstad kindergarten has been performed by analysis of the CO_2 the operative and air temperature and wind inside the room. The CO_2 was measured with Vaisala MI70 and Kimo instruments. The average CO_2 measured is very low because of the long periods that the kids spend outside and the high airflow rates that come in the Agora area. and by the time it arrives to the wings the velocity is already low enough. Velocities were measured with VelociCalc TSI 9555. To measure airflow rates a TSI Accubalance Air Capture Hood 8375 was used.

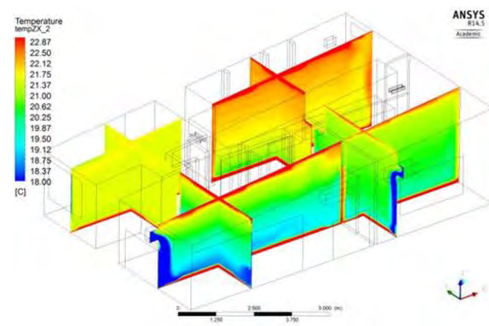


Fig. 17 RESULTS FROM CFD EVALUATIONS

Table 9 TABULATED VALUES FOR WINDOW OPENING FOR A TYPICAL DAY AS A FUNCTION OF TEMPERATURE AND WIND

Time	Tinteriot °C	Texterior °C	Wind speed m/s	Wind direction – 0.0 for N	Windows opening angle in Rødhette W	S
10:00	21.2	9.2	0.97	92.3	3.2	3.2
12:00	21.4	8.8	1.00	96.0	5.7	16.3
13:00	21.4	8.5	0.90	116.3	0.0	0.0
14:00	21.4	8.3	0.50	109.3	0.0	0.0
15:00	21.7	8.0	0.60	104.0	5.7	7.3

Table 10 PERCENTAGE HOURS EXCEEDANCE

Parameter	Year 2013	Year2014
Total Hours > 25°C	3%	5%
Occ Hours > 25°C	2%	2%
Total Hours > 28°C	1%	2%
Occ Hours > 28°C	0%	1%

7.2 Internal Temperatures

In the studied room there were measured during 2013, 66 hours with temperatures over 25 °C and only 5 hours with temperatures over 28 °C . For other rooms placed the results are similar, presenting the worst room 400 hours with temperatures over 25 °C but being most of these hours outside the occupied season. This room is placed on the second floor and these temperatures occur during holidays. Regarding temperatures, Figure 18 and 19, the times with measured higher temperatures, happen during periods with kids being on holidays and there may be some ventilation shut down. When windows are open during cold periods as shown in Fig 17, the risk of discomfort due to overcooling is higher. However, for outdoor temperatures such as in the simulation results, window would not open.

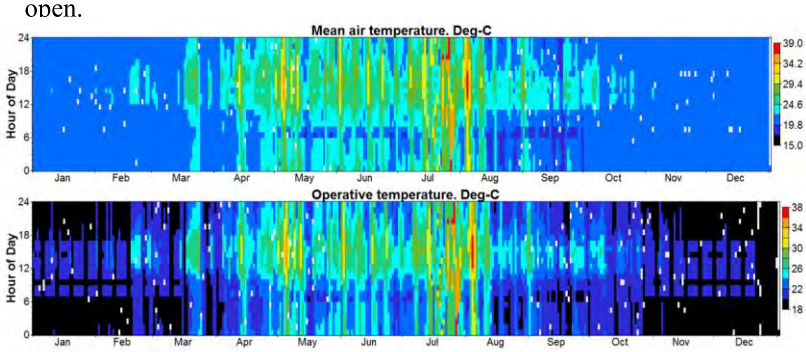


Fig. 18 INDOOR AND OPERATIVE TEMPERATURE PLOT

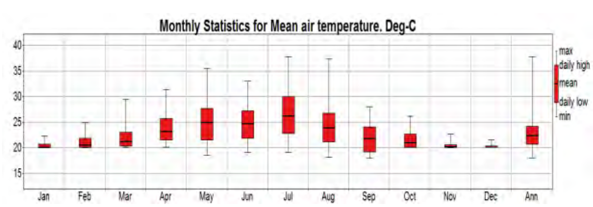


Fig. 19 INDOOR AIR TEMPERATURE PLOT

7. Performance Evaluation

7.3 Occupancy Profiles

The occupancy level in the building is very much constant during school period. The kids arrive every day between 7:30 and 8 and are inside the room until 9:30 when they go out for playing until 11:30 when they come back for eating lunch. They stay in the room till 14:00 when they get another outdoor playing time. The kids start then to leave at 15:30. During sunny days the playing take place outdoor, when the weather is too bad or too cold, the kids will play in the winter garden. The teachers are normally in the building till 16:30. There would be a maximum of 14 kids and 4 adults per wing.

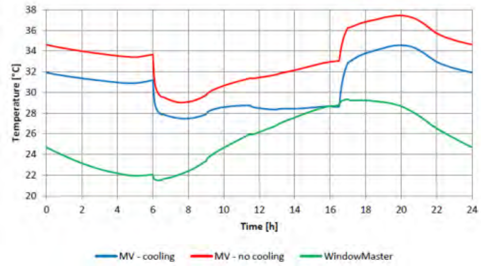


Fig. 20 MEAN INDOOR TEMPERATURE DISTRIBUTION IN AGORA FOR ALL THREE MODELS THROUGHOUT A DAY OF SYNTHETIC SUMMER CLIMATE

7.4 Performance simulations

The simulations performed in IDA Ice were compared to measurements in order to validate the model. The same model was used to compare energy use in case of having other cooling strategies such as using mechanical cooling, no cooling at all and Windows Master.

Analysis of the energy consumption shows that the Window Master model's total annual energy consumption is approximately 14 % lower than that of the conventional models, Table 11 shows the results. The main difference is in the HVAC auxiliary. The increase of energy consumption is natural as fan operation in the Window Master model is limited compared to the conventional models. The Window Master model has a slightly higher heating demand, that makes sense because of periods of window operation even during the winter season. When looking at the indoor climate, results from the synthetic summer climate simulation show that the Window Master solution provides lowest temperature for Agora, but also the highest temperature span during operating hours.

During simulations in synthetic winter climate, the indoor temperature stays in the region of the set point value for the heating system (20 °C) for all zones. There is however more temperature fluctuations for the WindowMaster solution as a result of small degrees of window operation. The simulations show fairly high CO_2-levels for all zones, but they are all within the set point values. As expected, there is little to no window operation during this simulation.

Table. 11 DELIVERED ENERGY COMPARISON

	MV - cooling Delivered energy [kWh/m²]	**MV - no cooling** Delivered energy [kWh/m²]	**Windows Master** Delivered energy [kWh/m²]
Electric heating	17.1	17.1	17.7
Electric cooling	0.7	0.0	0.00
HVAC auxiliary	10.3	11.0	2.5

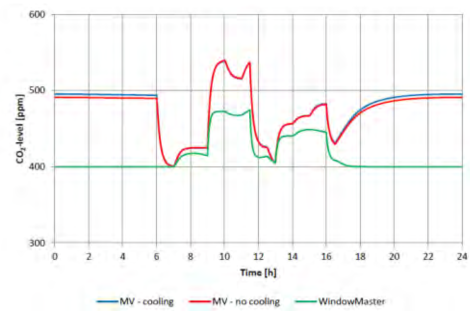
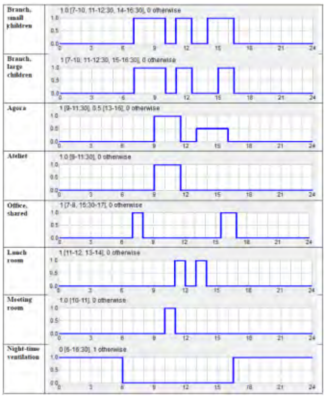


Fig. 21 MEAN CO_2-LEVEL DISTRIBUTION IN AGORA FOR ALL THREE MODELS THROUGHOUT A DAY OF SYNTHETIC SUMMER CLIMATE.



Zone	Maximum, occupancy [Nr]	Schedule, occupancy	Maximum, equipment [W]	Schedule, equipment	Maximum, lighting [W/m²]	Schedule, lighting
Gullhår	15	Branch, small children	1050	Opening hours	6.4	Branch, small children
Tyrihans	14	Branch, small children	1050	Opening hours	6.4	Branch, small children
Rodhette	21	Branch, large children	1050	Opening hours	6.4	Branch, large children
Askeladden	21	Branch, large children	1050	Opening hours	6.4	Branch, large children
Agora	15	Agora	450	Opening hours	6.4	Agora
Ateliet	5	Ateliet	450	Opening hours	6.4	Ateliet
Locker rooms, east	0	Never present	450	Opening hours	6.4	Opening hours
Locker rooms, west	0	Never present	450	Opening hours	6.4	Opening hours
Winter garden	0	Never present	0	Always off	0	Always off
Office, management	2	Opening hours	375	Opening hours	6.4	Opening hours
Office, shared	2	Office, shared	375	Opening hours	6.4	Office, shared
Lunch room	6	Lunch room	150	Lunch room	6.4	Lunch room
Meeting room	6	Meeting room	250	Meeting room	6.4	Meeting room
Hallway	0	Never present	480	Opening hours	6.4	Opening hours

Fig. 22 TYPICAL HEATING AND COOLING SEASON OCCUPANCY PROFILES

8. Lessons Learned

8.1 Summary

In climates as the Norwegian one, the risk of over cooling due to prolonged times with open windows has always to be evaluated. In order to control the risk of discomfort studies on draft should always be considered when working with VC. The window opening and how it affects total use of energy has also to be considered in detail.

Regarding the occupancy period, low CO_2 concentrations and some hours of temperature above comfort level were measured, but in total, the IAQ is high. Giving users the possibility to control and open windows has a positive effect on their perception of their indoor air quality.

It is important to have a good janitor taking care of the control of the system.

8.2 Detailed list of lessons learned

Table. 12 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	A detailed simulation model is important to simulate correctly for all conditions	H
2	The profit of having a complicated system with a higher cost should be better documented	M
3	Having several AHU enhances flexibility but increases investment and maintenance costs, a detailed evaluation should be done	L
4	The risk of overcooling has to be analysed in cold climates.	H

Table. 13 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	Overcooling happens more often than overcooling in the studied case	M
2	The system has to be maintained to avoid failures	H
3	The education of the janitor is very important for good performance of the system	M
4	Very good IAQ based on high enough ventilation rates and good heat recovery can be obtained with VC	H

9. References & Key Contacts

9.1 References

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Øgård, Y. G. (2014). Ventilative cooling for schools and kindergartens. Master thesis, NTNU.

Burzawa B, Justo Alonso, M, Mathisen, H M. 2016 "Case study hybrid ventilated kindergarten. Improvements in airflow patterns of natural ventilation with operable windows"(under review)

9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
NTNU	Project Research Team	Hans Martin Mathisen Hans.m.Mathisen@ntnu.no +4793059175
SINTEF Building and Infrastructure	Project Research Team	Maria Justo Alonso Maria.justo.Alonso@sintef.no +4794428591
Larvik kommune	Project owner	Per Sortedal Per.Sortedal@larvik.kommune.no +47 33 17 16 78
WindowMaster	Ventilation control	Vidar Henning Hansen vidarhh@bsi-as.no +4791145777

1.1 Introduction

MOMA apartment buildings , located in the central China, were completed in 2007. Fig.1 shows the external facades of the buildings. The ceiling radiant cooling panel (CRCP)with dedicated outdoor air system (DOAS) , which enable decoupling of the space sensible and latent loads,was applied for heating and cooling. The DOAS supply the ventilation requirements and remove the entire space latent load.The average thermal conductivity of the external wall is 0.54W/ (m^2K), the thermal conductivity of the external window is 2 m^2 (W/k) and the average window wall ratio is 0.28, the specific parameters are shown in Table 1.The main function of the window is for day lighting and normally closed, because the DOAS completely satisfies the demand of fresh air, we don't need open window avoiding outdoor polluted air into the indoor, the air inlets are located in the floor and the air outlet in the upside of the kitchen and the bathroom.

Fig.1 EXTERNAL FACADES OF THE BUILDING

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Changsha, China
Building Type	Residential
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Urban
Ventilative Cooling Strategy	Mechanical
Year of Completion	2007
Floor Area (m^2)	1108.62
Shape Coefficient (%)	20
Openable Area to Floor Area Ratio (%)	0
Window to Wall Ratio (%)	18
Sensible Internal Load (W/m^2)	56.9
Climate Zone (KG) (words?)	Cfa
No. of Days with T_e max > 25	84
Cooling Season Humidity	High
Heating Degree days (Kd)	2314

1.2 Local Climate

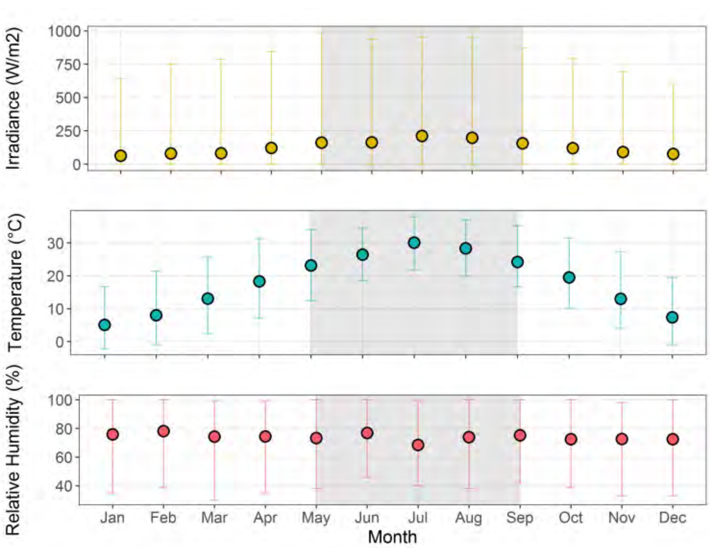


Fig.2 MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS IN CHANGSHA

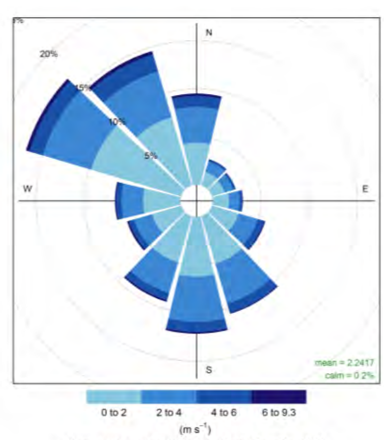


Fig.3 WIND ROSE FOR CHANGSHA

2. Building Information

2.1 Description

MOMA apartment building is an eighteen story apartment building with total floor area of 19955m2 . The concrete ceiling radiant cooling panels with dedicated outdoor air system was utilized to cooling, heating and ventilation.The tested rooms are located in the 14th and 18th floor, each room has a floor area of 130m2. The tested room plan shown in Figure 4, It is well known that the CRCP with DOAS is comfort and energy saving, air temperature in the room are more uniform. Compared with the full air system, the temperature of returning chilled water temperature increased, then the chiller performance increased, and the room temperature can improve 1~2 °C in the same comfort conditions.

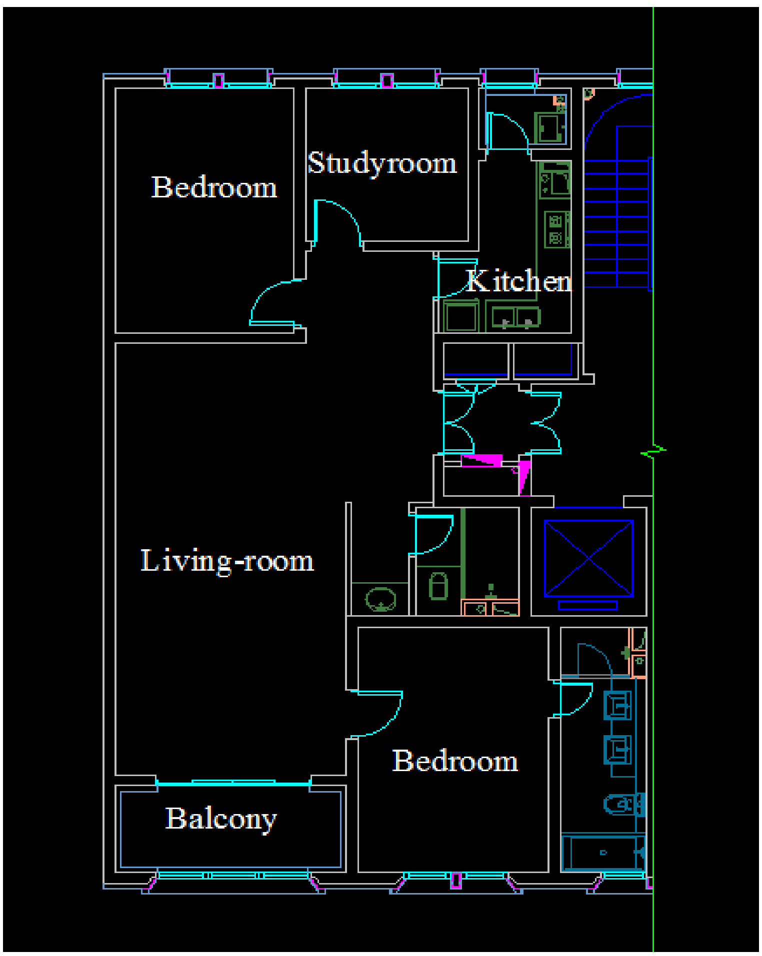


Fig 4. PLAN OF THE MEASURING ROOM.

Table.2 BUILDING PROPERTIES

Property	Unit	Value
Occupant density	m^2/p	30
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	34
Window U-value	W/m^2K	2.0
Window g-value	(-)	0.557
Wall U-value	W/m^2K	0.54
Roof U-value	W/m^2K	0.30
Floor U-value	W/m^2K	1.58
Thermal Mass (ISO 13790)	-	Very Heavy
Window to Wall Ratio	%	18
Air-tightness (@50 Pa)	1/h	1.5
Shape Coefficient (1/m)	%	20

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	●
Energy costs	●
Solar Loads	●
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	•
Burglary prevention	●
Privacy	•
Air Leakage	●

3. Energy Systems

The MOMA apartment buildings employed the ground source heat pump systems for summer cooling, winter heating and hot water to the whole year. The terminal is the CRCP with DOAS.

3.1 The radiant ceiling system

The radiant ceiling system, see the Fig.5, using two ground source heat pump units (GSHP-1、GSHP-2) as the cool and heat source, the air conditioning terminal is low temperature ceiling radiant panel. According to the area situation of the project, we buried the soil source pipe under the floor of the underground garage, total 402 wells which provide the energy for the ceiling radiant system, fresh air system and living hot water system. The effective depth of each well is 80 meters and the hole diameter is 130 millimeters, each well has double U parallel arrangement. Chiller units supply 16/21℃ chilled water and bypass 18/21℃ cold water for ceiling radiation in summer, supply 33/28 ℃ hot water and bypass 31/28 ℃ hot water for ceiling radiation in winter.

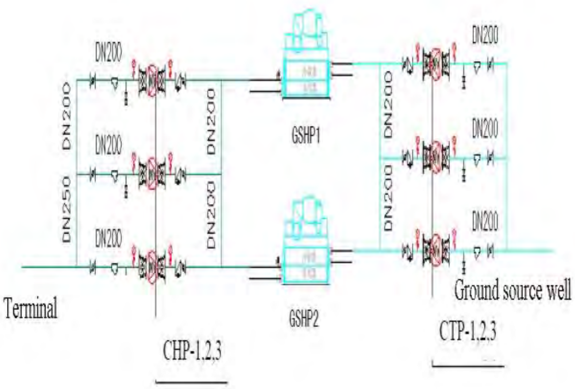


Fig. 5 PROCESS DIAGRAM OF RADIATION SYSTEM

3.2 The fresh air system

The fresh air system, se the Fig.6, is composed of two parts, one is the air supply and exhaust system, the other is the cool and heat water system. The fresh air supply and exhaust system consists of 8 units with heat recovery of fresh air units, each building has 4 units. The cold and hot water system for fresh air consist one sets of soil source heat pump air conditioner (GSHP-3) as cold and heat resource, summer cooling water from geothermal wells or cooling tower, cooling water supply and returning water temperature is 32/27 ℃, the chilled water supply and returning water temperature is 7/12 ℃. The ground source heat pump air conditioning unit in winter takes heat from the ground source to produce 45 /40℃ water supplying fresh air units to deal with outdoor fresh air.

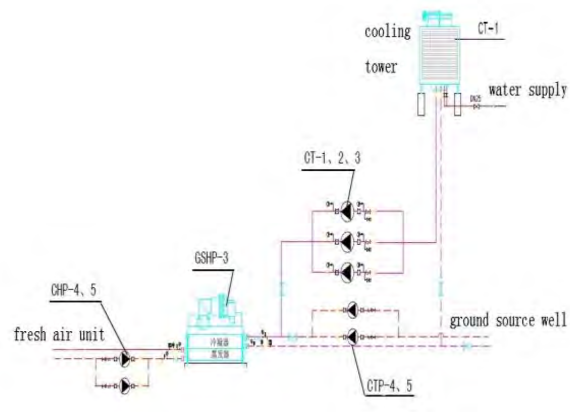


Fig. 6 PROCESS DIAGRAM OF FRESH AIR SYSTEM

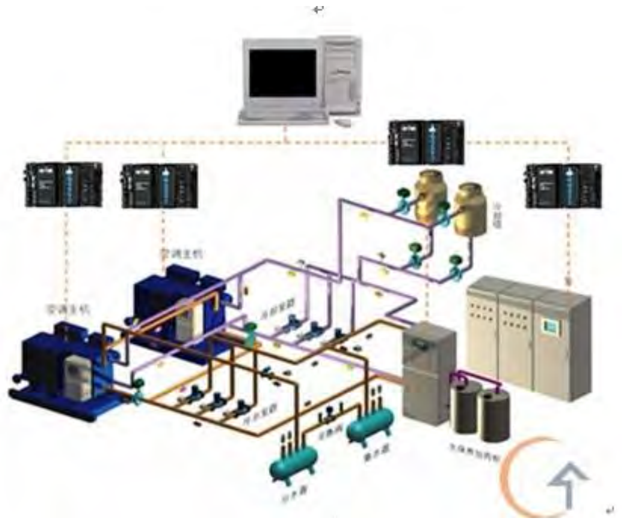


Fig. 7 THE FLOW CHART OF THE SYSTEM

4. Ventilative System

4.1 Introduction

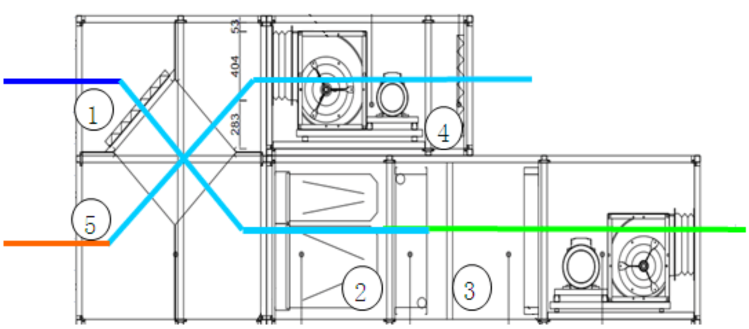
The mechanically ventilated system,with air inlet in the floor, was used to supply fresh air and exhaust air from the air outlet in the top of the kitchen and the bathroom. Ventilation connectors were utilized between rooms. The air tightness of the room is well to reduce the energy loss. When the outdoor temperature is lower than the design temperature of the air-conditioning system, increasing the frequency of fresh air system, which can supply a large number of low temperature outdoor fresh air to the room, increase the oxygen content and improve indoor air quality. With the outdoor temperature and the wet bulb temperature increased, reducing the operational frequency of fresh air units, reducing the chiller water temperature, besides the dehumidification capacity of air units were increased.

Fig. 8 AIR INLET AND OUTLET

4.2 Components

The tested room has a total of 6 fresh air inlets, 3 exhaust outlets and ventilation connectors were installed in the wall between rooms to make full use of fresh air. When the door is closed, the connectors ensure air circulation between rooms. Fig.9 shows the characteristic of the ventilation connector.To provide enough fresh air, four fresh air units were installed in the basement. Fig.10 shows the principle diagram of the fresh air unit.

Fig. 9 VENTILATION CONNECTOR



1.Fresh air 2.Filter 3.Surface Cooler 4.Exhaust fan 5.Air exhaust

Fig. 10 THE PRINCIPLE DIAGRAM OF THE FRESH AIR UNIT

5. Control Strategy

5.1 Control Strategy Overview

Building automation system is the key of the building, a perfect automatic control system not only can accurately make the mechanical and electrical equipment to play its predicted function, but also can extend the life of the equipment, to maximize the energy saving , Fig.11 presents the control strategy flowchart. Table 4 below lists the controlling parameters.

Table. 4 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/Target	Value
Indoor Temperature	Input	Variable
Indoor Set point Temperature	Target	24° C
Indoor Humidity	Input	Variable
Indoor Set point Humidity	Target	60%
Outdoor Temperature/Humidity	Input	Variable
Chilled Water Flow	Output	0% / 100%
Chilled Water Temperature	Output	Variable

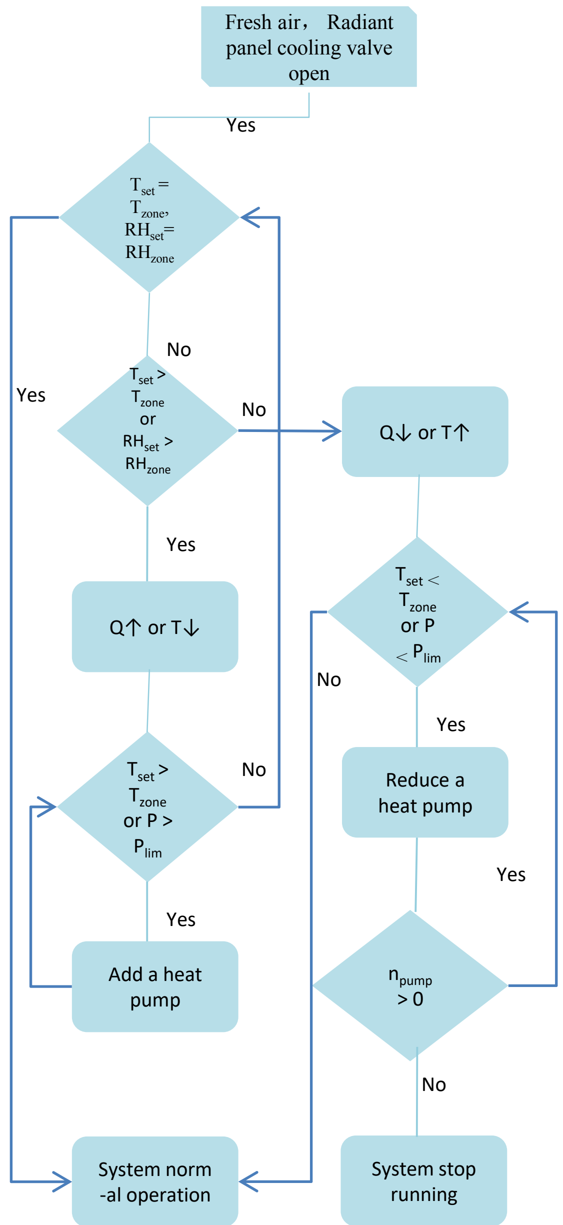


Fig. 11 AUTOMATED CONTROL FLOWCHART

5.2 Control Strategy Description

The high level automatic control of temperature and humidity are activated based on indoor temperatures and temperature difference between supply and return water. There are separated temperature sensors for each room and pipe in building. The system was operated according to the next sequency, firstly run a refrigerator, secondly according to the indoor temperature and the temperature difference between supply and return water calculate the actual needs of the cold quantity, if the system load reaches a refrigerator 90% then run another refrigerator, finally, when the cold load requirement less than 50% of each unit, close one refrigerator. The main influence of the system operation is the following :

•Indoor temperature
•Outdoor temperature
•Temperature difference between supply and return water
•Occupants'thermal sensation.

6. Operate Simulation

6.1 Summary

In the design stage, the indoor air distribution and temperature field are simulated by means of CFD software to guide to design CRCP system. In actual operation, the simulation data and the measured data were compared to verify the correctness and analyzes the indoor temperature distribution and airflow organization, which providing help for improving indoor air quality and the indoor thermal comfort.

Table. 5 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	35.8° C
T_z , Summer Operative Temp	25° C
Overheating criteria	$T_z < 28$° C for 99% hr_{occ}
Min IAQ air supply rate	10 ls^{-1} /pers
Cooling air supply rate	30 ls^{-1} /pers
Noise Level Rating	35dB

6.2 Simulation of overheating risk

Through simulation, we can conclude that indoor thermal comfort will be enhanced if we elevate the temperature by 1-2℃ of the radiant ceiling. In addition, the laying rate of radiant ceiling is very important to indoor thermal comfort. Higher laying rate will increase the cost and have little influence to thermal comfort, but lower laying rate will lead to the risk of condensation and have a great impact on thermal comfort. So taking into account the cost of radiant ceiling, the laying rate of radiant ceiling should be the range 60-80%.

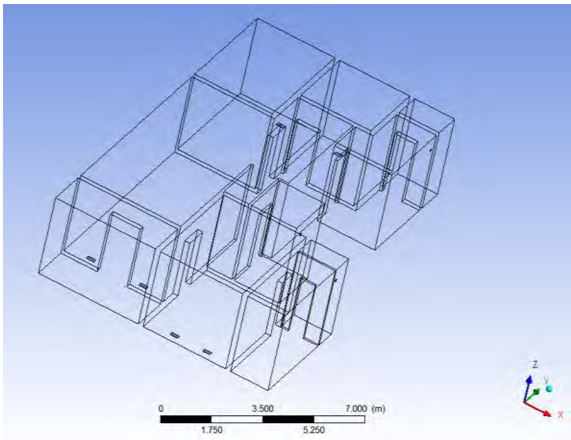
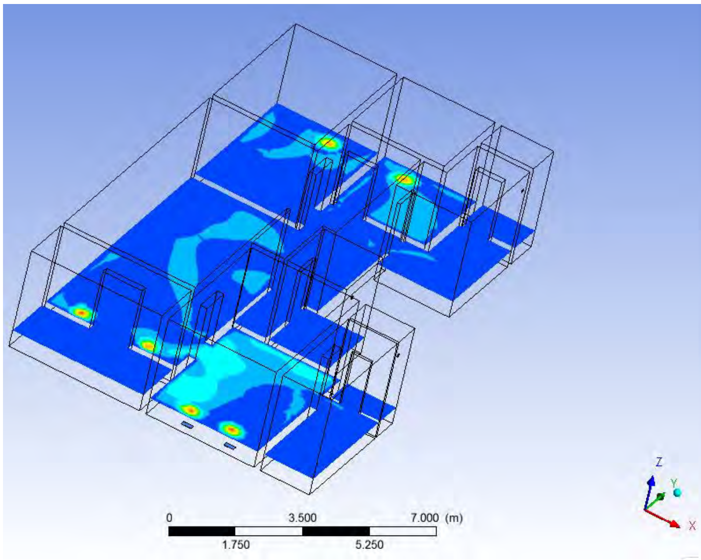


Fig. 12 SIMULATION MODEL OF MOMA

6.3 Simulation of ACR



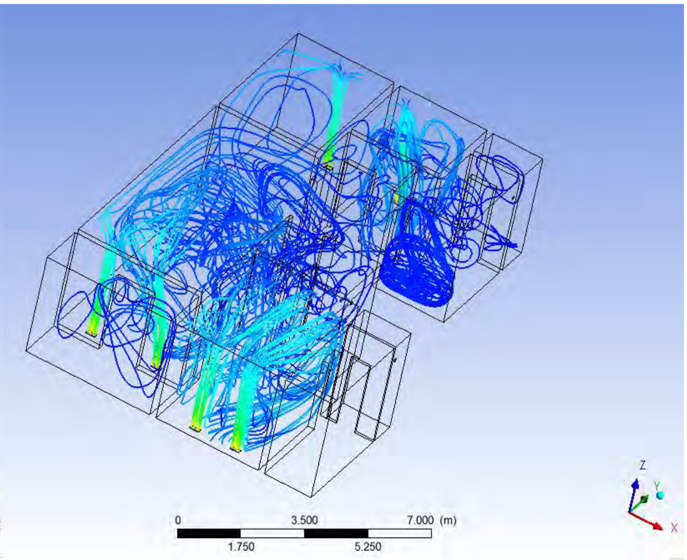


Fig. 13 OPERATION STAGE SIMULATION: TEMPERATURE FIELD & AIR DISTRIBUTION

7. Performance Evaluation

7.1 Supply and return water temperature of ceiling radiant panel

circulating pumps of CRCP system are variable flow operation. The supply and return water temperature of the CRCP system is 18/21℃in summer , 28/31℃ in winter. when the ceiling system's supply and return water temperature difference is lower than 2 ℃, ceiling system circulating pump with variable frequency and variable flow operation, while adjusting the ceiling system water valve, reducing cooling load. The supply and return water temperature difference of the ceiling radiant panel heat pump unit for cooling season is 2.91℃ and the average COP of the unit is 5.20.

7.2 Supply and return water temperature of fresh air unit

The initial stage of cooling season, when the outdoor temperature is lower than the indoor design temperature of air-conditioning system, increase fresh air and exhaust fan frequency, supplying plenty of low temperature outdoor fresh air into the room to decrease the temperature, increase the oxygen content, improve air quality and reduce the running time of the chilled unit; during the cooling season, when the outdoor temperature increased, reduce the frequency of operation of fresh air units to reduce the supply water temperature, then the dehumidification capacity of fresh air units increases, when supply and return water temperature difference is less than 2 ℃, regulating the water flow, increasing the heat capacity of the surface cooler. The supply and return water temperature difference of the fresh air heat pump unit for cooling season is 2.70 ℃ and the average COP of the unit is 3.44.

7.3 Internal Temperature

Indoor air temperature distribution is uniform, the vertical temperature difference is small, the maximum temperature difference of air temperature is 1.7 ℃ during the test, the temperature fluctuation standard deviation is 0.296. Figure 15 shows the air temperature distribution in the central of the room at four moments, from 0.1 m to 2.1 m the air temperature distribution is more uniform, the vertical air temperature increases first and then decreases near the middle height reaches the maximum value, near the floor and the top plate position the air temperature drop.

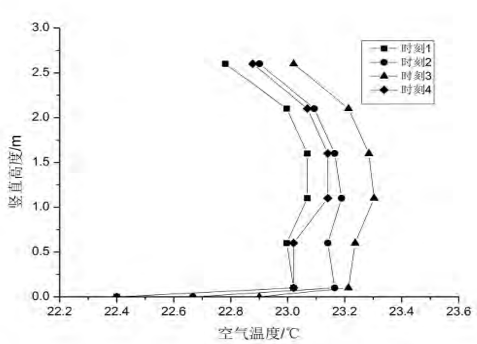


Fig. 16 INDOOR INDOOR AIR TEMPERATURE DISTRIBUTION IN THE VERTICAL DIRECTION

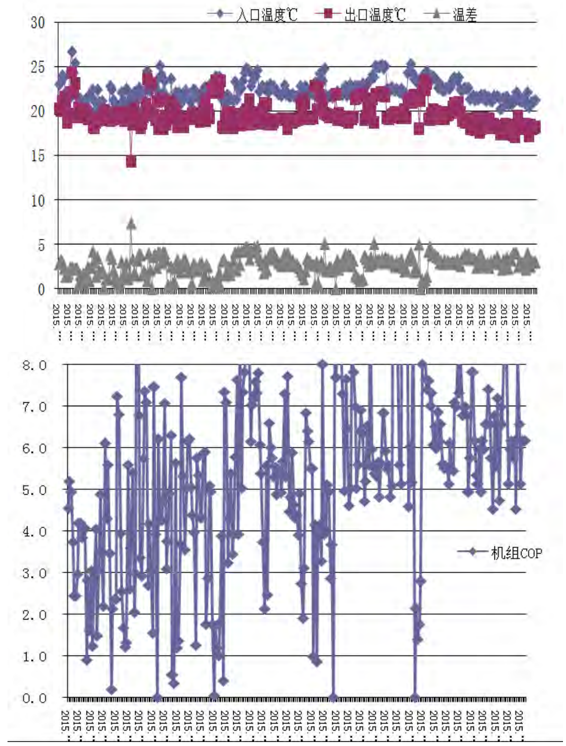


Fig. 14 THE RADIATION SYSTEM OPERATION CONDITION

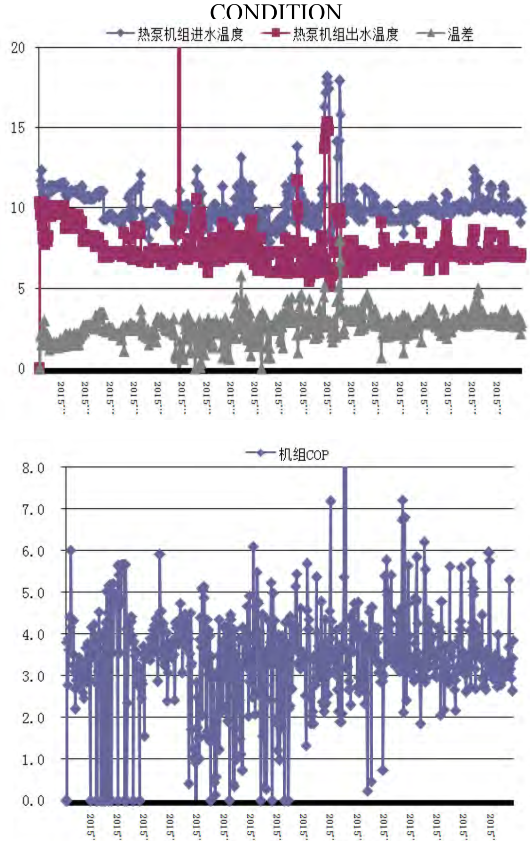


Fig. 15 FRESH AIR SYSTEM OPERATION CONDITION

7. Performance Evaluation

7.4 Thermal Comfort

The 100 questionnaires were collected from this test, including 40 women and 60 men. Fig. 17 shows the result of thermal sensation vote during this Experiment, through the statistical analysis of the questionnaire it is concluded that 93% of the subjects consider acceptable thermal environment including neutral, slightly warm and slightly cool. Calculation of the measured data by the experiment, indoor PMV value between -0.95 to -0.5, PPD <22 %, which means slightly cool, the main reason for this is the room currently uninhabited, basically no heat source, only testers and recording equipment, the actual cooling load is lower than the design cooling load. Table.6 shows local thermal discomfort statistics, the average floor (ceiling) surface was about 22.53 °C (22.05 °C) and the standard deviation was about 0.596 °C(0.562°C), the average temperature difference for the surfaces with the greatest differential about 1.44°C. With the small differences among surface temperatures, the radiant temperature asymmetry should be within 5°C. Therefore, the ratio of participants dissatisfied with radiant temperature asymmetry should be less than 5% and as low as zero, meeting the requirements of ISO 7330.
We also do some questionnaire about local thermal sensation of human body, addressing subject's local thermal sensation in six local body area(i.e. head , chest, back , arms, legs and feet), finding local thermal sensation of subjects accord with normal distribution, different parts of body (except foot) have slight difference of thermal sensation to the environment, Fig. 19 shows the result of local thermal sensation vote.

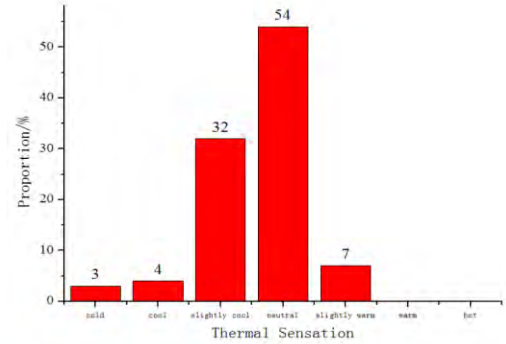


Fig. 17 OVERALL THERMAL SENSATION VOTE

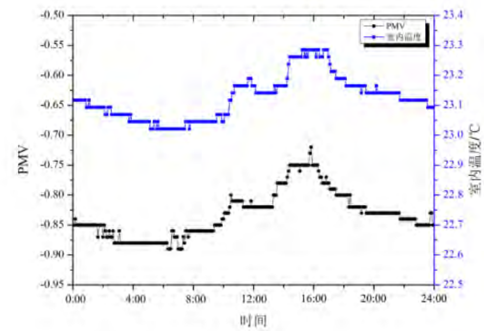


Fig. 18 INDOOR PMV

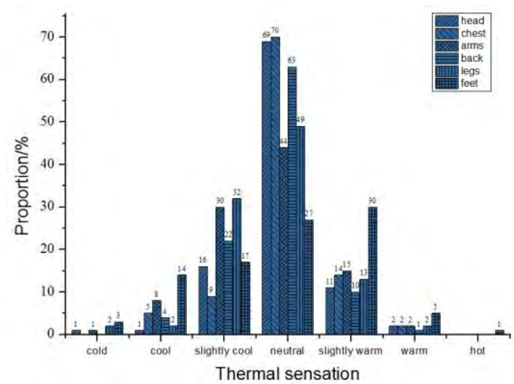


Fig. 19 LOCAL THERMAL SENSATION VOTE

7.4 Occupancy Profiles

The occupancy level in the residential building is dependent on the schedules of residents. During the cooling season occupancy in the building is on average at 4 people during occupied hours (18:00 – 7:00), in transitional season the occupancy level will lower during 18:00 –21:00, this difference in transitional season is due to the temperature outside which is pleasant, people are willing to go out and take a walk, so the occupancy level would go down.

Table.6 LOCAL THERMAL DISCOMFORT PARAMETERS STATISTICS

Parameter	Mean	Max	Min	S.D.
Vertical air temperature difference（1.1-0.1m）/℃	0.25	0.81	0	0.195
Floor temperature/℃	22.53	23.8	20.4	0.596
Ceiling temperature/℃	22.05	23.5	20.3	0.562
Temperature difference between ceiling and floor/℃	0.47	1.6	-0.6	0.502
Maximum temperature difference between walls/℃	0.51	1.0	0.2	0.162
Maximum temperature difference between wall and floor/℃	1.44	1.9	0.8	0.203

8. Lessons Learned

8.2 Detailed list of lessons learned

Table. 8 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	A detailed evaluation of the building location, building structure and heat/cool load during the concept phase was essential to adapt CRCP system to the building.	High
2	Integrated design with frequent exchange with the planning team was essential to develop the most suitable technical solution.	High

Table. 9 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1 User controlling	It is important that user can control the indoor terminal device for thermal comfort and energy saving.	High

9. References & Key Contacts

9.1 References

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2. Sodec F. Economic viability of cooling ceiling systems. Energy & Buildings, 1999, 30(2):195-201.
3. Stetiu C. Energy and peak power savings potential of radiant cooling systems in US commercial buildings. Energy & Buildings, 1999, 30(2):127-138.
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5. Qi J K. Evaluation of energy conservation potential and complete cost-benefit analysis of the slab-integrated radiant cooling system: A Malaysian case study. 2015.

9.1 Key Contacts

Table. 10 KEY PROJECT CONTACTS

Company	Role	Contact
Hunan university	Client & Project Research Team	Jie han hanjie@hnu.edu.cn +86 731 88821040
Modernland Real Estate Co., Ltd	Project Engineers	Xiaozheng Li 13910303241@139.com

1.1 Introduction

The Austrian Federal Building Owner BIG developed a modernisation strategy for its buildings from the 1950s to 1980s. The main aspects of the strategy are high energy efficiency of the building envelope, thermal comfort in winter and summer, possibility for natural ventilation and optimised investment costs. The faculty building of the Faculty of Technical Sciences of the University of Innsbruck was built in 1969. It is one of two pilot projects for the test application of the sustainable retrofit strategy for federal buildings. The major renovation was completed in 2014. The ventilation solution for the retrofit involved a concept of ventilative night cooling of the offices to guarantee high occupant comfort in summer. Newly developed automatically operable windows and air flow valves are key elements of the ventilation concept.
The main aim of the renovation was a high sustainability standard, which was verified by achieving the enerPHIT standard of the Passive House Institute, and to upgrade the building to state-of-the-art occupant comfort.

Fig.1 University of Innsbruck – Faculty of Technical Sciences, Austria, Photo Credits: ATP/Thomas Jantscher

Table.1 Key Information about building

Location	Innsbruck, Austria
Building Type	Education
Retrofit (Y/N)	Y
Surroundings (Urban / Rural)	Suburban
Ventilative Cooling Strategy	Mixed
Year of Completion	2014
Floor Area (m²)	12530
Shape Coefficient (%)	18
Openable Area to Floor Area Ratio (%)	6.9
Window to Wall Ratio (%)	37.9
Sensible Internal Load (W/m²)	5.06
Climate Zone (KG) (words?)	Dfb
No. of Days with T_e max > 25	63
Cooling Season Humidity	65.6%
Heating Degree days (Kd)	3430

1.2 Local Climate

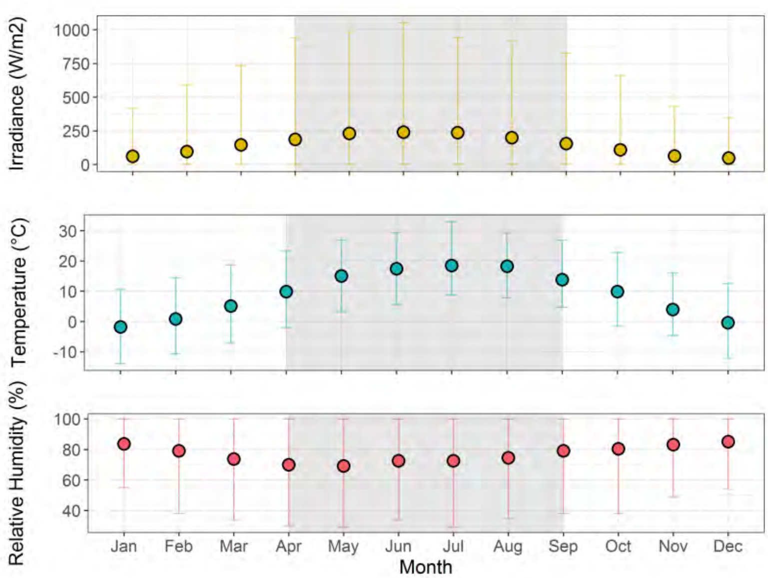

Fig.2 Mean, maximum and minimum external conditions at Innsbruck University using TMY3 from Meteonorm 7 (cooling season shown shaded)

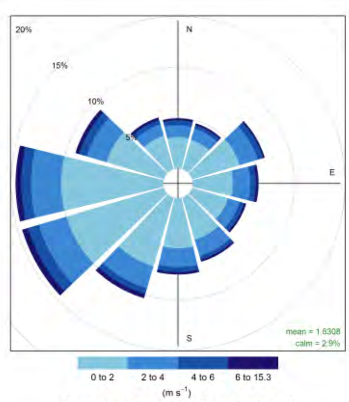

Fig.3 Wind rose for Innsbruck

2. Building Information

2.1 Description

The building with its tower shape represents a landmark on campus. It is an ashlar building with 8 floors and a basement of which the 7 identical upper storeys house offices and faculty administration, while the ground floor and adjoining buildings are used for education and studies. Office areas in the regular floors are located in the fringe area along the façades, while the building centre contains sanitary installations, electrical connections and infrastructure.
Due to the East-West orientation and the location of the building with solar radiation of 1250 – 1350 kWh/m^2, solar gains in summer cause a high risk of overheating. The retrofit contained the installation of a completely new façade with automatically operable windows for natural ventilation and ventilative cooling.

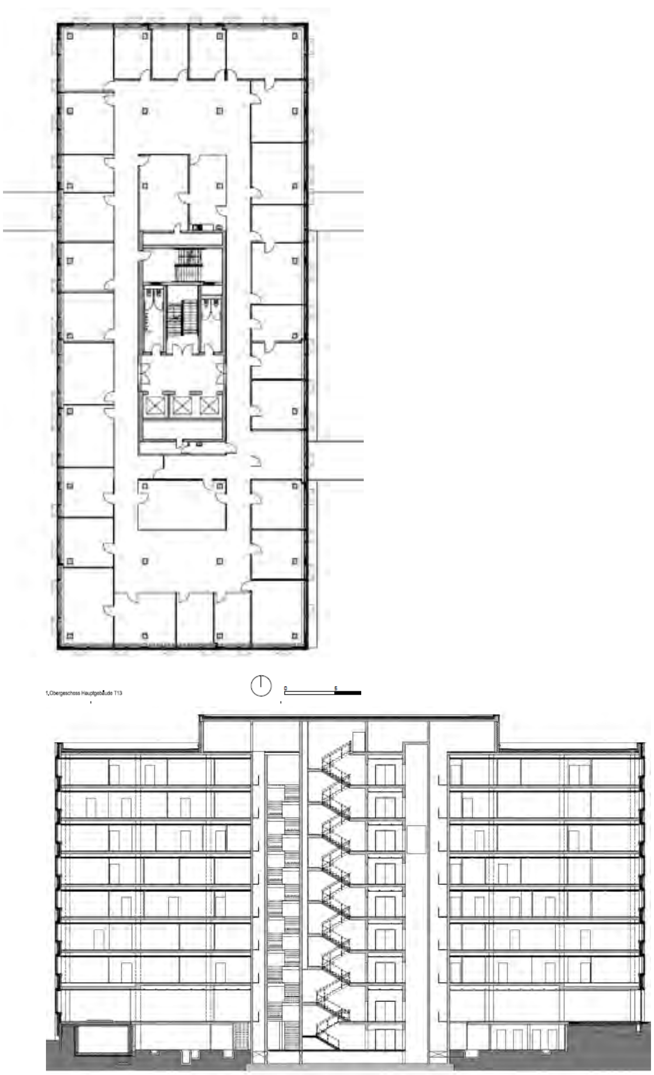

Fig 4. Top of image conveys standard floor plan.
Bottom of figure illustrates the cross section of the building.
Source: ATP architekten ingenieure

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	34.3
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	5.06
Window U-value	W/m^{2}K	0.75 – 0.80
Window g-value	(-)	0.30
Wall U-value	W/m^{2}K	0.150
Roof U-value	W/m^{2}K	0.150
Floor U-value	W/m^{2}K	0.192
Q-value (from Japan)	(W/ m^2)/K	
Thermal Mass (ISO 13790)	-	Heavy
Window to Wall Ratio	%	37.9
Air-tightness (@50 Pa)	1/h	0.61
Shape Coefficient (1/m)	%	18

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	⬤
Energy costs	⬤
Solar Loads	●
Internal Loads	•
External Noise	●
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	⬤

3. Energy Systems

The faculty building is connected with the campus-own local district heating network for heat supply. By the use of ground water for pre-conditioning supply air, a cooling machine could be excluded from the technical concept.

3.1 Heating System

The heating system is supplied by the campus-own local district heating plant with primary temperatures of 95°C/75°C. Due to the reduced heating need after the retrofit the building's transfer station could be reduced from 1400 kW to 670 kW and the secondary system temperatures decreased from 90°C/70°C to 75°C/60°C. The heating circuits have been renewed, while the heat distribution system within the building has not been changed during retrofit as displayed in Figure 6. The existing plate radiators were retained but thermostatic valves have been added.

Fig. 5 GROUND WATER WELL, PHOTO CREDITS: ATP ARCHITEKTEN INGENIEURE

3.2 Cooling System

By pre-conditioning the supply air of the seven ventilation systems with ground water (see Figure 5). As not necessary, the originally planned compression refrigeration machine with a capacity of 121 kW was not implemented.

Fig. 6 EXISTING HEAT DISTRIBUTION SYSTEM, PHOTO CREDITS: ATP ARCHITEKTEN INGENIEURE

3.3 Electrical Power Supply (PV, wind turbine & Microgrid)

There is no electricity generation system installed on the building site. However, preparations have been made during construction works to add a PV system at a later time.

4. Ventilative Cooling

4.1 Principles

During night automatically operated window openings on all four façade directions allow cool exterior air to flow into the fringe area of the building. Stored heat from building masses is transported either by buoyancy via the same window openings directly to the exterior or, in case of higher thermal loads, via airflow openings above the doors into the building center, where the exhaust air vents support the air circulation and transport the heat to the exterior.

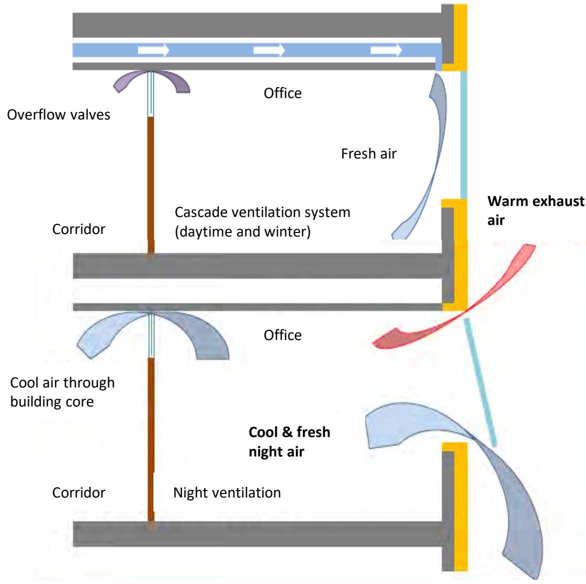

Fig. 7 Ventilative cooling principle, Source: Passivhaus Institut, Edited: E7

4.2 Components

The ventilation solution for the retrofitted building consists of top-hung projecting-out windows which open and close automatically according to wind conditions and cooling requirements. Each window hinge section contains two operable elements with sizes 1.56m x 1.90m and 1.25m x 1.90m, with a maximum opening width of 35 cm. In total more than 300 top-hung windows have been installed.
Airflow openings above the doors (overflow valves) provide flow paths from the fringe to the central zone of the building. The exhaust air vents of the mechanical ventilation system can be used to increase the air flow from exterior to interior.
Both the windows and the overflow valves have been newly developed for the application in this building.

Table. 4 Components capacity dimensioning

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area	0.49 m² 0.38 m²
Discharge Coefficient (Cd)	0.6
Overall Dimensions	1.90m x 1.56m 1.90m x 1.25m
Porosity (A_w/A_f)	1.31%
Q (@ Vel = / ΔP =	0.03 m³/s

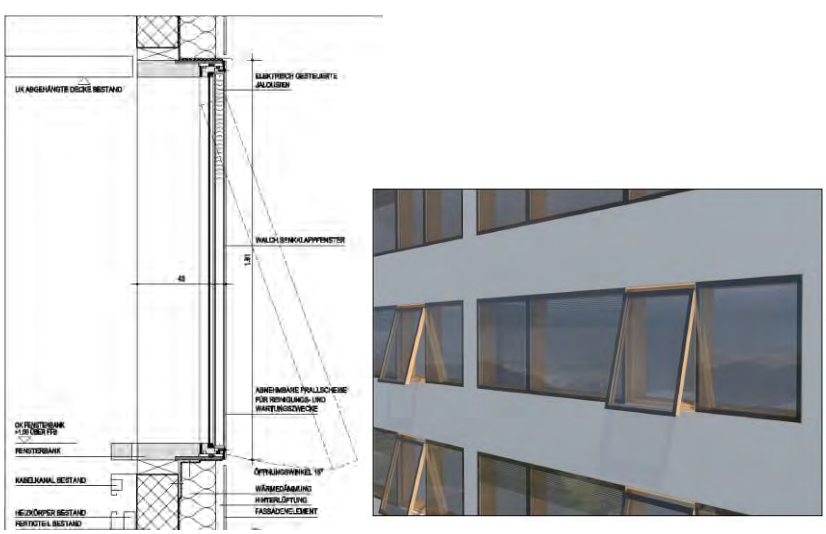

Fig. 9 Custom-made top-hung projecting-out windows, Source: Passivhaus Institut

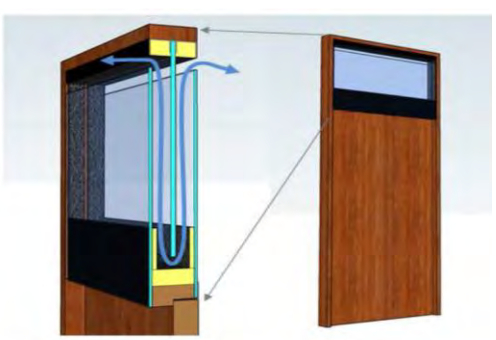

Fig. 8 custom-made Airflow Openings, Source: Passivhaus Institut

5. Control Strategy

5.1 Control Strategy Overview

The Control strategy for the ventilative cooling system is largely based on the actuation of the automated windows. All four cardinal directions are controlled separately. The exhaust air vents support the air flow and are operated based on specific control parameters.
Figure 10 presents the control strategy flowchart. Table 5 below lists the controlling parameters.

Table. 5 CONTROL STRATEGY TABLE IF NEEDED

Parameter	Input/Output/Target	Value
Zone Temperature	Input	Variable
Zone Setpoint Temperature	Target	20°C
Night Cooling zone set point	Target	20°C
External Temperature	Input	Variable
External Temperature low limit	Target	18°C
Ventilation Door Position	Output	0% / 100%

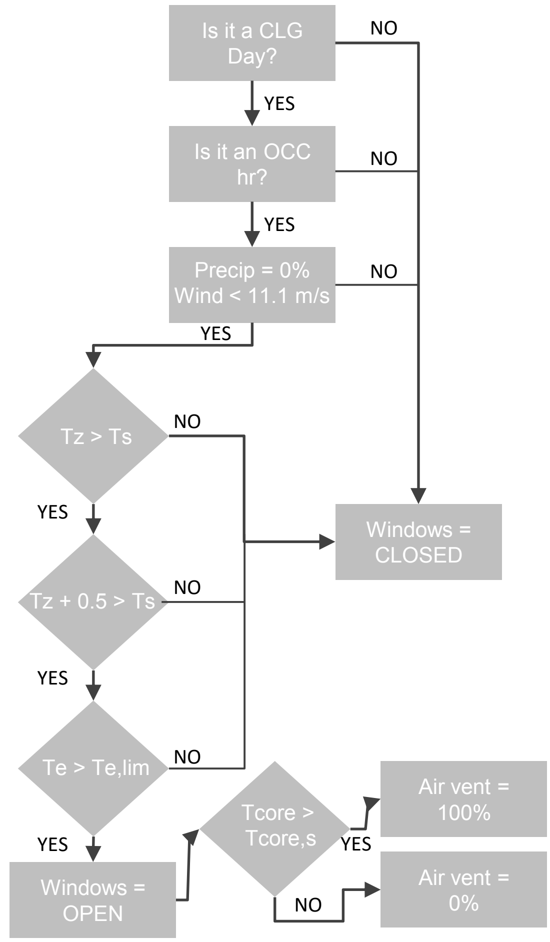

Fig. 10 AUTOMATED WINDOW CONTROL FLOWCHART

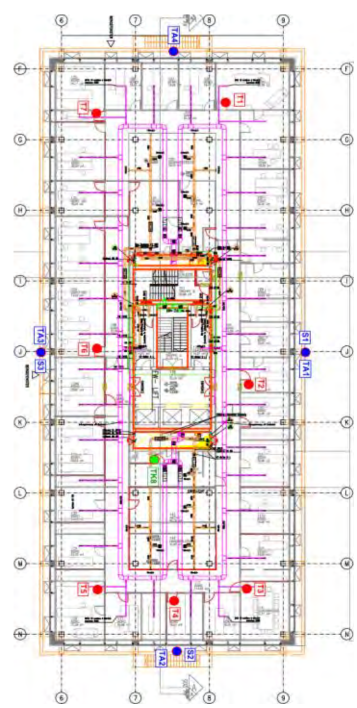

Fig. 11 FLOOR PLAN WITH TEMPERATURE SENSORS, SOURCE: ATP ARCHITEKTEN INGENIEURE

5.2 Control Strategy Description

The automated windows are actuated based on the difference between internal zone temperatures and exterior temperatures. There are dedicated single zone temperature sensors for indicative rooms in the building (highlighted in red in Figure 11) and temperature sensors for exterior temperature along the facade (highlighted in blue in Figure 11). When the following conditions are met the window positions are driven to the fully open position.

- date and time within predefined ranges
- zone temperature above a certain value
- external temperature within a certain range
- precipitation and wind conditions below a certain value

The exhaust air vent is turned on 100 % power if all above parameters are fulfilled and temperature measured in the building centre (sensor highlighted in green in Figure 11) is above a certain value.

Local override is available for manual control of the high level automated openings during operation hours and during times without night ventilation.

6. Design Simulation

6.1 Summary

The main aims of the design stage simulation were to analyse the thermal behaviour of the building in summer, the results of the ventilation concept and to predict the effectiveness of the developed building elements.
To guarantee reliable simulation results a detailed survey of internal loads in the existing building and a specification of technical parameters of windows and the ventilation concept have been completed prior to the simulation.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	PHPP	Define Building Element Quality, Energy Performance
Concept Design	Dynbil	Thermal Analysis, Energy Performance
Concept Design	TRNSYS	Thermal Analysis, Energy Performance, Parameter Studies

6.2 Simulation of overheating risk

The simulation showed that the retrofit reduces the risk of overheating to 0.5%. In total during 48 hours per year temperatures rise above 26°C, as displayed in Figure 14.

6.3 Simulation of ACR

A simulation of ACR has not been performed. However, a simulation of opening widths of windows in relation to indoor air temperature has been performed. It showed that an average air flow of 120 m^3/h, which is necessary to keep indoor air temperatures below 27 °C, could only be achieved with an opening width of 35 cm (maximum opening width) of the top-hung windows and would not be possible with standard bottom hung windows.

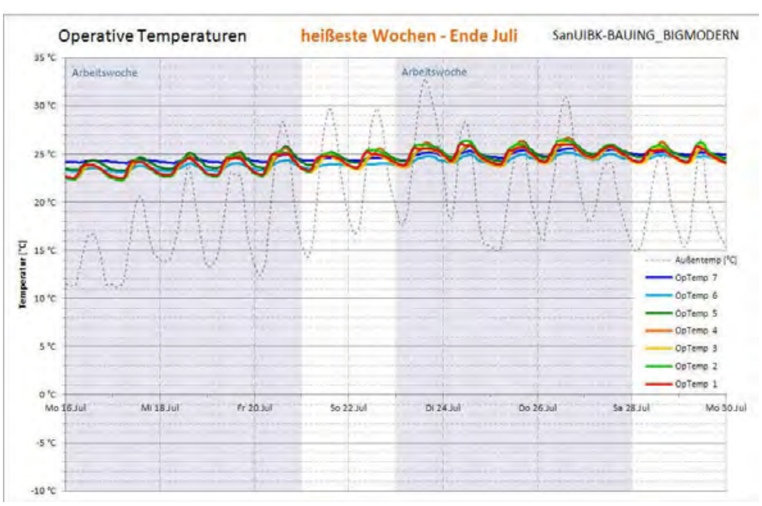

Fig. 14 ZONE TEMPERATURES DURING HOTTEST WEEKS IN JULY, RESULTS FROM DESIGN STAGE SIMULATION, SOURCE: PASSIVHAUS INSTITUT

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	34.0
T_z , Summer Operative Temp	27.0
Overheating criteria	T_z < 26°C for 95% hr_{occ}
Min IAQ air supply rate	1 – 4 h^{-1} according to room type
Cooling air supply rate	min. 2.5 h^{-1}
Noise Level Rating	-

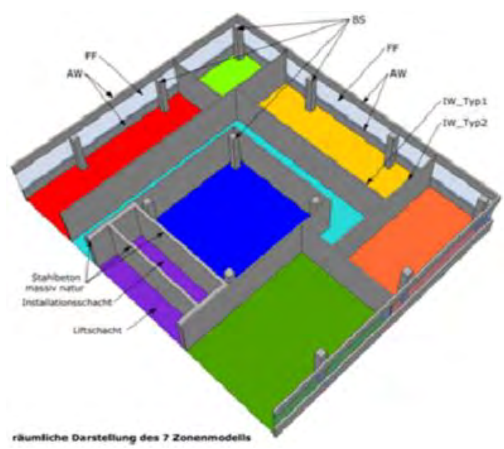

Fig. 12 DESIGN STAGE SIMULATION OF RETROFITTED BUILDING USING DYNBIL, SOURCE: PASSIVHAUS INSTITUT.

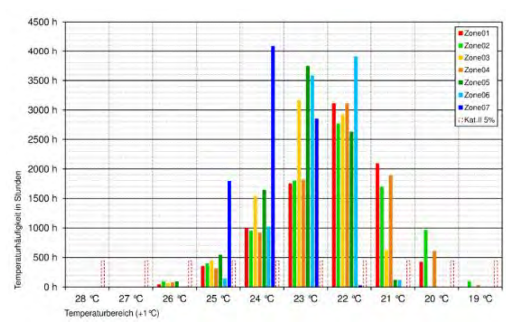

Fig. 13 TIME-WEIGHTED ZONE TEMPERATURES, DYNBIL, SOURCE: PASSIVHAUS INSTITUT.

7. Performance Evaluation

7.1 Ventilative Cooling Potential

The building's renovation was completed in 2014 and from November 2014 onwards monitoring data on internal temperatures in reference rooms, window position, electricity consumption of the supporting exhaust fans and weather data was gathered. The data analysis is ongoing as part of a scientific research project called BIGMODERN.
The following analyses take into account the period from 01.04.2015 until 30.09.2015, which is characterized by very hot temperatures during summer months.
Except for July when nighttime temperatures frequently exceeded 22 °C, the maximum possible operation time of ventilative cooling lay between 260 and 310 hours per month. Figure 15 shows that external temperatures are suitable for ventilative cooling almost during the whole cooling period in Innsbruck.

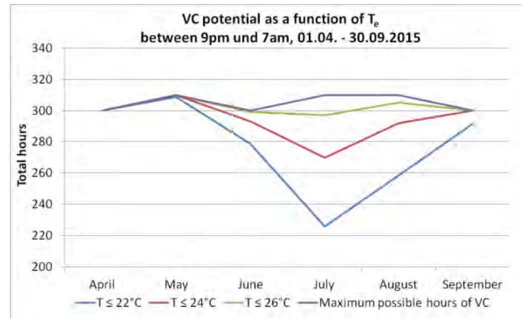

Fig. 15 POTENTIAL FOR VENTILATIVE COOLING IN INNSBRUCK IN 2015 IN RELATION TO EXTERNAL TEMPERATURE

7.2 Internal Temperatures

Internal air temperatures have been measured and recorded in 8 reference rooms, from which two are located in the building core. Room 701 on the north-eastern corner of the seventh floor was selected as show case, as it reached the highest overall temperatures and the largest overheating periods in 2015. Figure 16 displays the percentage of occupancy hours exceeding the temperature thresholds of 26 °C (orange) and of 28 °C (red). While temperatures above 28 °C hardly occurred, the internal temperature exceeded 26 °C around 50% of occupancy hours in April and July 2015, while the rest of the months showed few overheating periods. The same fact can also be seen in Figure 17, which shows the carpet plot of the internal temperature for Room 701. Dark red areas mark temperatures above 27 °C, which occur predominantly in April and July.

Table 9 PERCENTAGE HOURS EXCEEDANCE

Parameter	Average over all measured rooms Apr – Sept 2015	Room 701 Apr – Sept 2015
Total Hours > 25°C	21.63	31.88
Occ Hours > 25°C	32.40	55.79
Total Hours > 28°C	0.51	0.62
Occ Hours > 28°C	1.14	1.52

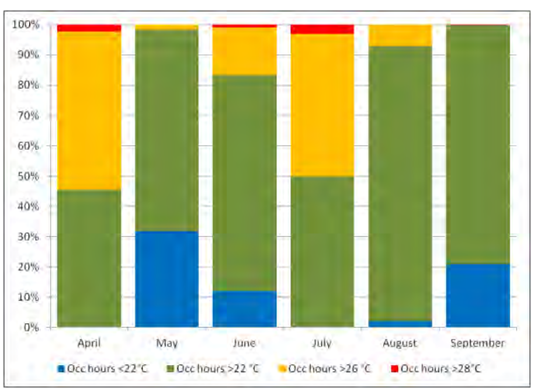

Fig. 16 PERCENTAGE OF OCCUPANCY HOURS ABOVE THRESHOLD VALUES FOR INTERNAL TEMPERATURES IN ROOM 701 DURING 2015

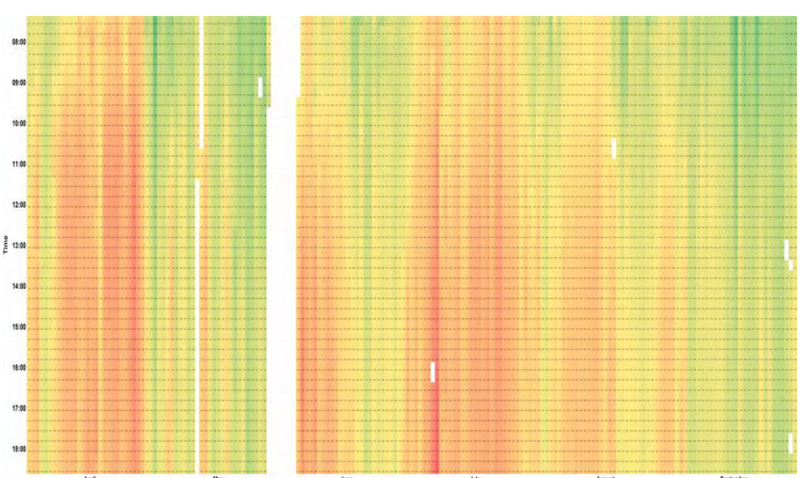

Fig. 17 INDOOR AIR TEMPERATURE PLOT IN R701 APRIL – SEPTEMBER 2015

7. Performance Evaluation

7.3 Internal temperature profiles

To evaluate the effectiveness of the ventilative cooling system, the internal temperature profiles of the reference rooms have been compared with the window automation signal. Figure 18 displays the results for selected reference rooms and one of the hottest periods in July 2015. The graph shows a significant decrease of internal temperatures when the window position is 1 (open). The maximum temperature drop amounted to 4 K. At the same time the graph displays a striking increase of internal temperatures in the building core (rooms 130 and 435) over weekends, when the ventilative cooling is not in operation.

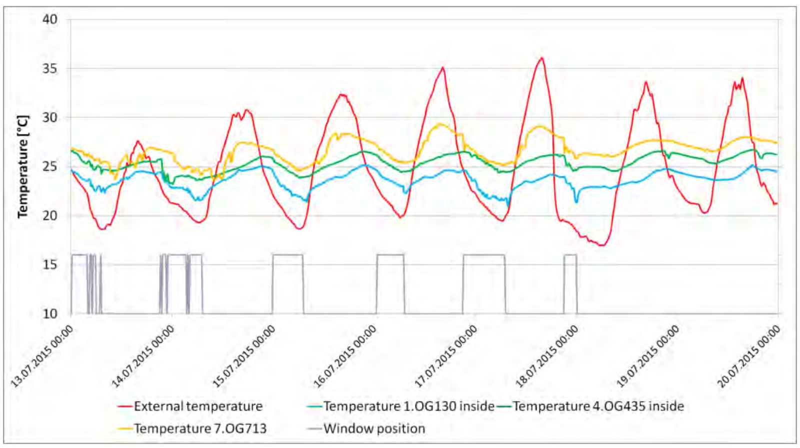

Fig. 18 Internal temperature profile Rooms 130, 435, 713 in July 2015

7.4 Exhaust air vents

The buoyancy-driven ventilative cooling system is supported by exhaust air vents of the two mechanical ventilation systems when the building's core temperature exceeds 25 °C. In Figure 19 and 20 the total operation hours of the ventilative cooling system are displayed. Figure 20 compares the operation hours with the electricity consumption caused by the exhaust air vents that support the ventilative cooling. Electricity input for ventilative cooling amounts to 5,000 kWh in 2015. Interestingly, in July, which was the hottest month with the most ventilative cooling operation hours, the electricity consumption is lower than in June or August 2015. As air flows of the buoyancy-driven ventilative cooling mode have not been measured, the cooling capacity could not be calculated.

7.5 Occupancy profiles

Typically occupancy hours are from Monday to Friday from 07:00 am until 08:00 pm, with core hours from 07:00 am to 05:00 pm. During core hours in the cooling season occupancy is on average 41 people per standard floor. In the cooling season the occupation is approximately 70% of the heating season. In peak times 365 people use the building. Data is based on the building operators information as no electronic registration system is installed.

Fig. 19 Operation Hours of Ventilative Cooling in 2015

Table. 10 VC hours and corresponding electricity consumption

Month	Hours of natural night ventilation	Electricity consumption [kWh]
April 14	15.25	107
May 14	116.50	927
June 14	135.75	1180
July 14	171.50	841
August 14	152.25	1115
September 14	98.25	830

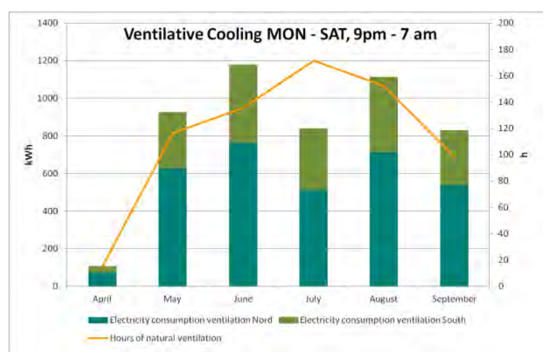

Fig. 20 Electricity consumption of VC supporting exhaust air vents

8. Lessons Learned

8.1 Summary

The evaluation during the scope development phase, especially if the location provides the necessary environment for ventilative cooling applications, was key to design an efficient tailor-made technical building system including ventilative cooling. Both technical and economic aspects boosted the ventilative cooling application. Integrated design that also included the future building user was key to the successful planning and operation of the ventilative cooling system in Innsbruck.

8.2 Detailed list of lessons learned

Table. 12 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	A detailed evaluation of the building location, building structure and its operation profile during the concept phase was essential to adapt the ventilative cooling system to the building.	High
2	Integrated design with frequent exchange within the planning team was essential to develop the most suitable technical and economical solution.	High
3	Custom-made elements had to be used for the specific application due to required air flow rates. Sufficient time for the planning phase, element development and testing was crucial for success.	High
4	The ventilative cooling system is more cost-efficient over the building's lifetime than a conventional cooling system. Maintenance costs of the chosen components have substantial influence on life-cycle costs.	High
5	Design simulations are essential to proof the developed concept already during the planning phase.	Moderate

Table. 13 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	The future building operator should be already involved in the planning phase to receive know how regarding the technical building systems and its projected features. He is the key actor for handling the technical building systems and building optimisation.	High
2	The system performs well and provides the required indoor air comfort. However regulation parameters need to be monitored and optimized on a regular basis to assure high user comfort.	High
3	A lower external temperature limit for ventilative cooling than 18 °C would significantly increase the potential operation time of ventilative cooling and increase its effectiveness. Too low internal temperatures in the morning seem not to be a problem based on monitoring data.	Moderate

9. References & Key Contacts

9.1 References

C. Kuh, G. Benke, G. Hofer, K. Leutgöb: BIGMODERN Subprojekt 9. Demonstrationsgebäude Universität Innsbruck – Umsetzung. Leitprojekt: Nachhaltige Sanierungsstandards für Bundesgebäude der Bauperiode der 50er bis 80er Jahre. Berichte aus Energie- und Umweltforschung 30/2015. Bundesministerium für Verkehr, Innovation und Technologie. 2015.

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W. Feist, et al.: Integrale Planung einer thermischen Sanierung eines Universitätsgebäudes nach EnerPHit-Standard. Protokollband Nr. 48. Einsatz von Passivhaustechnologien bei der Modernisierung von Nichtwohngebäuden. Arbeitskreis kostengünstige Passivhäuser. Passivhaus Institut und Universität Innsbruck. 2012.

9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
Bundesimmobiliengesellschaft m.b.H.	Client	Bertram Knoflach bertram.knoflach@big.at +43 5 0244 5708
ATP sphere GmbH	Project Architect	Paul Ohnmacht paul.ohnmacht@sphere.ag +43 512 5370 4008
Passivhaus Institut – Standort Innsbruck	Building Physics	DI Harald Konrad Malzer h.k.malzer@phi-ibk.at +43 680 321 9032
ATP Innsbruck Planungs GmbH	General planer	Hans Kotek hans.kotek@atp.ag +43 512 5370
Starmann Metallbau GmbH	Facade, fenestration	Mr. Falk office@starmann-metallbau.at +43 463 420 480
Siemens Aktiengesellschaft Österreich	Building Management System	Daniel Bernhard Vogt Bernhard.vogt@siemens.com +43 5170 70

1.1 Introduction

Windkraft Simonsfeld AG is a supplier of renewable electricity. Its main business activities are planning and operating wind power plants and to a lesser extent solar power plants in Austria and Southeast Europe. The company's new headquarter was finished in 2014 and it underlines the idea of a sustainable and modern company. The 967 m^2 building has an envelope in passive house quality and has a positive annual energy balance. One of the central design aspects is the optimized technical building system that maximizes the use of local resources. The concept also includes a ventilative cooling system in the central building zone, which comprises 24 automated openings and four supporting tornado-fans on the roof. As it is a flagship project for plus-energy buildings the design phase, construction phase and first years of operation were subject of a scientific research project.

Fig.1 Headquarter of Windkraft Simonsfeld, Ernstbrunn, Austria, Photo Credits: M.O.O.CON/Helge Bauer

Table.1 Key Information about building

Location	Ernstbrunn, Austria
Building Type	Office
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Mixed
Year of Completion	2014
Floor Area (m^2)	967
Shape Coefficient (%)	64
Openable Area to Floor Area Ratio (%)	7.9
Window to Wall Ratio (%)	22.23
Sensible Internal Load (W/m^2)	7.6
Climate Zone (KG) (words?)	Cfb
No. of Days with T_e max > 25	58
Cooling Season Humidity	59.95%
Heating Degree days (Kd)	3430

1.2 Local Climate

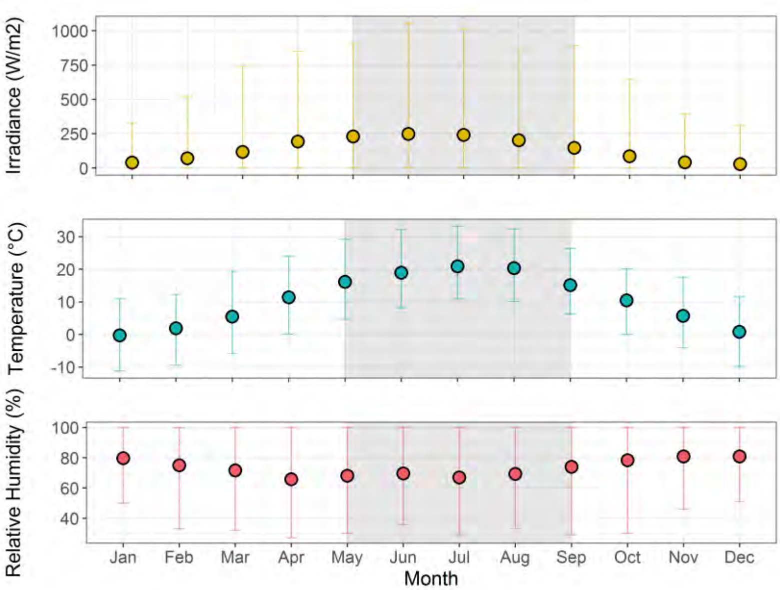


Fig.2 Mean, maximum and minimum external conditions at Ernstbrunn using TMY3 from Meteonorm 7 (cooling season shown shaded)

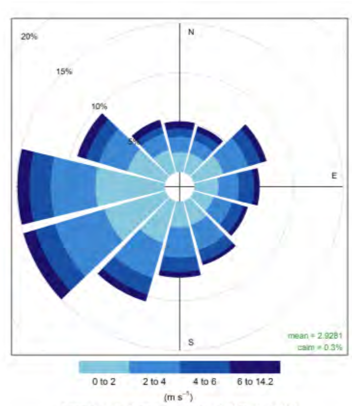


Fig.3 Wind rose for Ernstbrunn

2. Building Information

2.1 Description

The headquarter consists of an office building and storage areas. It is optimized to its location by its half-round southern glass façade, which optimizes solar gains through window areas and solar panels. This area is built as an atrium that hosts the entrance, social areas and meeting rooms. The north and east façades are mostly opaque to reduce heat losses. In the back area of the building offices are located. The roof area and southern façade are used for solar power generation for both domestic hot water and electricity.

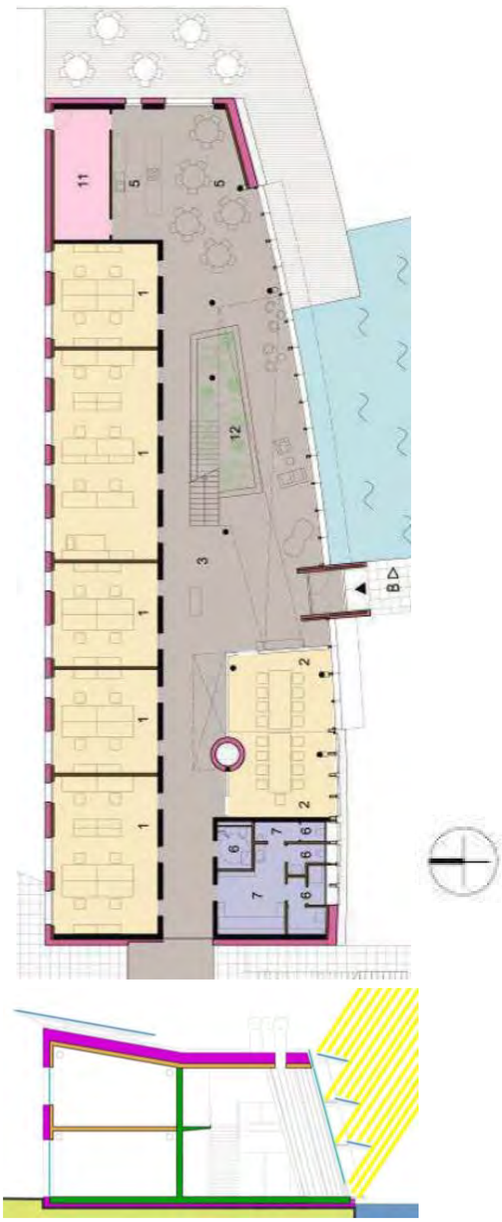


Fig 4. Top of image conveys Ground Floor Plan.
Bottom of figure illustrates the Cross Section of the Building.
Source: Architekturbüro Reinberg ZTGmbH

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	38,4
Hours of occupancy	h/week	62,5
Sensible Internal Load	(W/m^2)	7.6
Window U-value	W/m^2K	0.77 – 0.98
Window g-value	(-)	0.34 – 0.47
Wall U-value	W/m^2K	0.14 – 0.16
Roof U-value	W/m^2K	0.10
Floor U-value	W/m^2K	0.15
Q-value (from Japan)	$(W/m^2)/K$	
Thermal Mass (ISO 13790)	-	Moderate
Window to Wall Ratio	%	22.23
Air-tightness (@50 Pa)	1/h	0.56
Shape Coefficient (1/m)	%	64

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	⬤
Energy costs	⬤
Solar Loads	●
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	•
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	⬤

3. Energy Systems

The Windkraft Simonsfeld headquarters utilize independent energy systems for electrical and thermal requirements. The system is designed to generate more energy than is need on an annual balance.

3.1 Heating System

The heating system comprises a 100 m^2 solar thermal system for heating and domestic hot water generation with a total of 3.500l hot water storage in combination with a ground source heat pump, which gathers the geothermal energy through 11 geothermal probes. The maximum heating power output of 20 kW with an annual COP of 4. The heat distribution consists of a floor heating and heating registers in the ventilation system. The system is controlled on a common return water temperature. The system is also operated on a demand-oriented time schedule.

Fig. 5 VENTILATION SYSTEM, PHOTO CREDITS: ARCHITEKTURBÜRO REINBERG ZTGMBH

3.2 Cooling System

The office areas are cooled by passive cooling from the geothermal probes without using the heat pump. The cool water is distributed primarily through the floor heating. Additionally, component activation is in place in the central building area to activate building masses for cooling. The meeting room on the ground floor is equipped with two chilled beams.
In cases when temperatures of the probes reach the limits for cooling, the heat pump can be used to reduce the primary temperature of the coolant and disperse excess heat via an additional heat exchanger. The server room uses a passive cooling system based on a ground water circulation with fan coils. The ventilative cooling system is installed in the atrium area and consists of automated openings and tornado fans.

Fig. 6 FAÇADE-INTEGRATED PHOTOVOLTAIC PANELS, PHOTO CREDITS: ARCHITEKTURBÜRO REINBERG ZTGMBH

3.3 Electrical Power Supply (PV, wind turbine)

A 50 kWp photovoltaic power system is installed on the building, which generations an estimated 49,430 kWh electricity per year that is used on site. A low-speed wind turbine is installed to power a ground water pump.

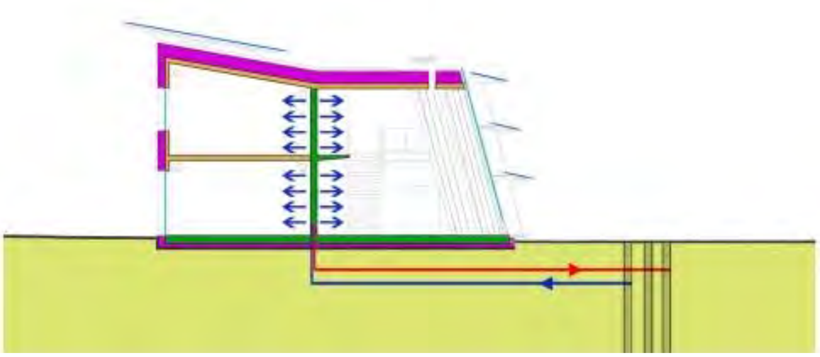


Fig.7 GEOTHERMAL HEATING AND COOLING THROUGH COMPONENT ACTIVATION, ARCHITEKTURBÜRO REINBERG ZTGMBH

4. Ventilative Cooling

4.1 Principles

Ventilative cooling is installed in the central atrium area to reduce overheating risks. Semi-automated openings with grills on the outside in the south-oriented façade allow exterior air to enter. Four tornado fans on the roof increase the air flow based on the interior temperature. The ventilative cooling system is designed to reduce the capacity of the free cooling system with ground water. The results of the building simulation showed that a free opening area of 8 m^2 is required to provide the designed air flow.

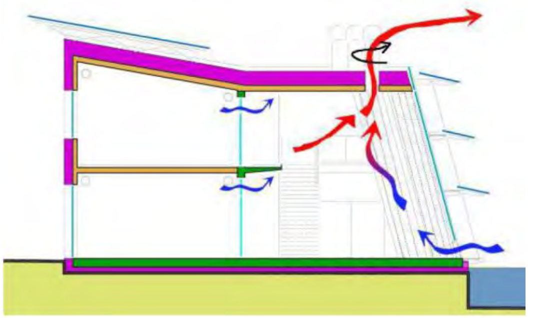


Fig. 8 VENTILATIVE COOLING PRINCIPLE, SOURCE: ARCHITEKTURBÜRO REINBERG ZTGMBH

4.2 Components

The ventilation solution for the plus-energy building consists of bottom-hung projecting-in openings which open and close automatically according to temperature conditions. In total 24 openings with a size of 1.2m x 0.55m, with a maximum opening width of 36 cm are installed in the lower part of the south-facing façade.
Four tornado fans with a capacity of are installed on the roof over the atrium area to enhance the air flow.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Guiding and enhancing
Free opening area	0.42 m^2
Discharge Coefficient (Cd)	Not measured
Overall Dimensions	1.2m x 0.55m
Porosity (A_w/A_f)	1,15%
Q (@ Vel = / ΔP =	0.04 m^3/s

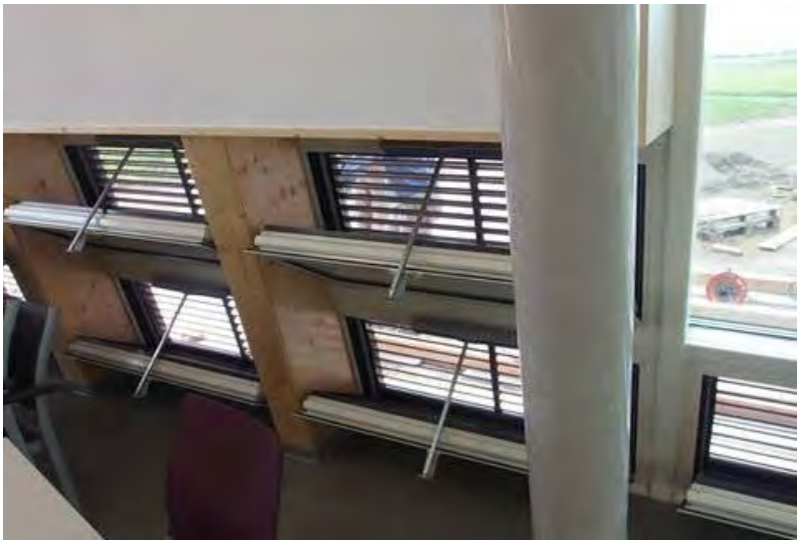


Fig. 10 BOTTOM-HUNG PROJECTING-IN OPENINGS, SOURCE: ARCHITEKTURBÜRO REINBERG ZTGMBH

Fig. 9 TORNADO FANS, SOURCE: ARCHITEKTURBÜRO REINBERG ZTGMBH

5. Control Strategy

5.1 Control Strategy Overview

The control strategy for the ventilation system is largely based on the actuation of the automated openings in the south-oriented façade. The tornado fans are gradually activated depending on the interior temperature. Figure 11 presents the control strategy flowchart. Table 5 below lists the controlling parameters.

Table. 5 CONTROL STRATEGY TABLE IF NEEDED

Parameter	Input/Output/Target	Value
Zone Temperature	Input	Variable
Zone Setpoint Temperature	Target	23°C
Night Cooling zone set point	Target	23°C
External Temperature	Input	Variable
External Temperature low limit	Target	Not limited
Ventilation Door Position	Output	0% / 100%

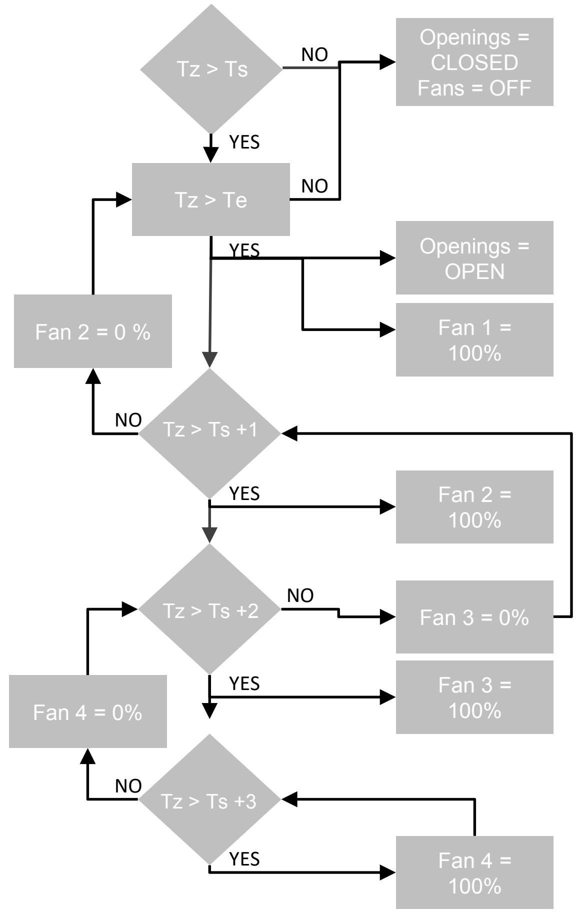


Fig. 11 AUTOMATED OPENING CONTROL FLOWCHART

5.2 Control Strategy Description

The automated openings are actuated based on the difference between internal zone temperatures and exterior temperatures. There are zone temperature sensors for the atrium and a temperature sensor for exterior temperature. When the following conditions are met the window positions are driven to the fully open position.

- zone temperature above a certain value
- external temperature lower than zone temperature

With the activation of the openings, the first of four tornado fans is turned on 100 % power. The other three fans are controlled gradually according to the internal zone temperature. Each Kelvin of temperature increase activates another fan. When the internal temperature decreases again the fans shut down in reverse order. With the last fan turning off, the openings close.

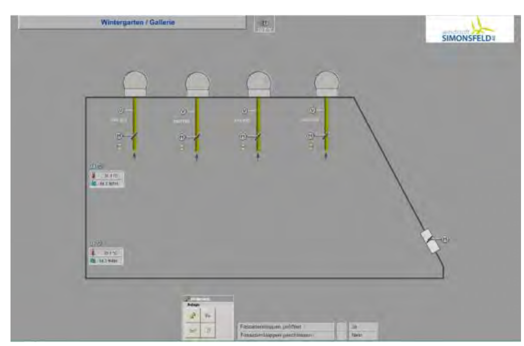


Fig. 12 SIEMENS BUILDING AUTOMATION SYSTEM, VENTILATIVE COOLING, SOURCE: SIEMENS AKTIENGESELLSCHAFT ÖSTERREICH

6. Design Simulation

6.1 Summary

The main aims of the design stage simulation were to analyse the thermal comfort in the building during summer and winter and to verify the positive energy balance by analysing the building's energy performance. To guarantee reliable simulation results the simulation was updated several times during the design process.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

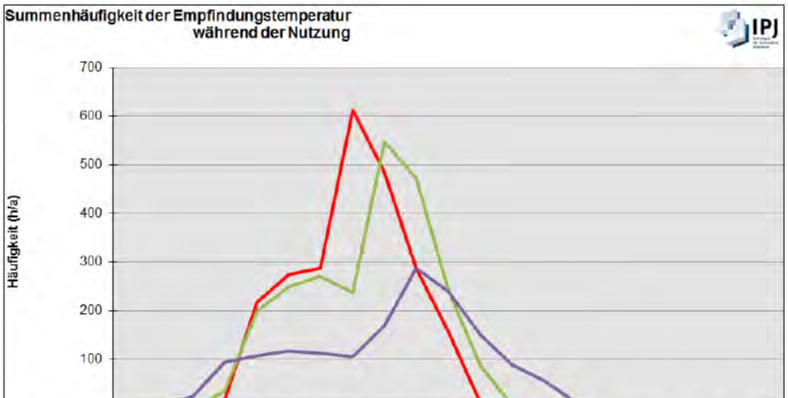
Stage	Tool	Function
Concept Design, Detailed Design	Tas 9.2	Thermal Analysis, Loads, Energy Performance, Parameter Study
Construction Design	PHPP	Energy Performance

6.2 Simulation of overheating risk

The simulation showed that the technical building system provides a high thermal comfort with minimal overheating risks. The temperature in the offices spaces never exceeds 28 °C and only a few hours 26 °C. Figure 15 shows that the temperature in the gallery reaches a maximum of 29 °C. On the hottest day of the year the meeting room on the upper floor peaks at close to 30 °C as can be seen in Figure 14.

6.3 Simulation of cooling energy need

The simulation resulted in a cooling energy need of 8,440 kWh per year, which occurs between May and September . The cooling energy need is mainly covered through the free cooling ground water system .



	15°C	16°C	17°C	18°C	19°C	20°C	21°C	22°C	23°C	24°C	25°C	26°C	27°C	28°C	29°C	30°C	31°C	32°C	33°C	34°C	35°C
Wintergarten	0	0	0	16	217	273	287	611	483	287	155	11	0	0	0	0	0	0	0	0	0
Galerie OG	0	0	0	33	198	249	270	237	547	472	241	87	6	0	0	0	0	0	0	0	0
Besprechung OG	0	2	24	94	107	117	112	106	168	287	238	150	88	56	11	0	0	0	0	0	0

Fig. 15 CUMULATIVE FREQUENCY OF FELT TEMPERATURES DURING OCCUPANCY HOURS PER YEAR, RESULTS FROM DESIGN STAGE SIMULATION, SOURCE: IPJ INGENIEURBÜRO P. JUNG GMBH

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	34.5
T_z , Summer Operative Temp	24.0
Overheating criteria	$T_{z,office} > 26.0$ $T_{z,gallery} > 29.0$
Min IAQ air supply rate	8.3 ls^{-1}/pers
Cooling air supply rate	8.3 ls^{-1}/pers
Noise Level Rating	-

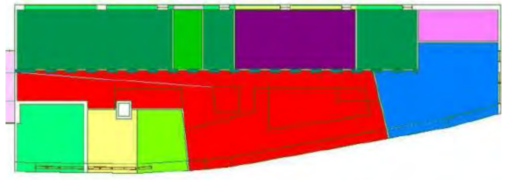


Fig. 13 DESIGN STAGE SIMULATION, GROUND FLOOR USING TAS 9.2, SOURCE: IPJ INGENIEURBÜRO P. JUNG GMBH

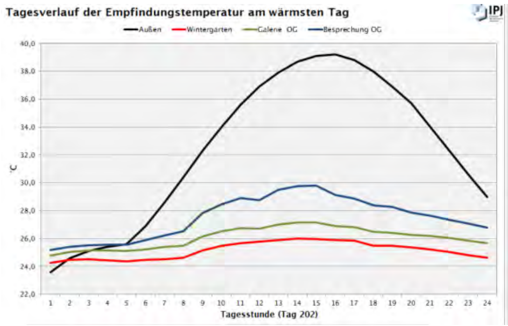


Fig. 14 ZONE TEMPERATURE ON THE HOTTEST DAY, TAS 9.2, DESIGN STAGE SIMULATION, SOURCE: IPJ INGENIEURBÜRO P. JUNG GMBH.

7. Performance Evaluation

7.1 Overheating

Internal air temperatures have been measured and recorded in all rooms. The following graphs present the gallery on the south-facing area where the ventilative cooling system is installed. Figure 16 displays the percentage of occupancy hours above threshold values. The graph shows that temperatures range between 22 and 26 °C during the whole period. Overheating never occurred due to the operation of an active cooling system in combination with ventilative cooling.

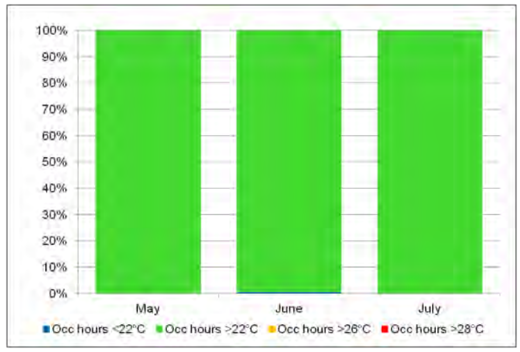


Fig. 16 Percentage of occupancy hours above threshold values for internal temperatures in gallery, May – July 2015

7.2 Internal temperatures

The carpet plot shows the internal temperatures during occupancy hours from May to July 2015 for the gallery. The internal temperatures strongly correlated with external temperatures even though an active cooling system is in operation. Dark red areas mark temperatures between 25.8 and 26.0 °C, which occurred in the first half of June and during two weeks in July. Data recording did not work well at the beginning of the recording period, which caused regular gaps in the data.

Table 9 Percentage hours exceedance in gallery

Parameter	May – July 2015
Total Hours > 25°C	16.0
Occ Hours > 25°C	20.0
Total Hours > 28°C	0.0
Occ Hours > 28°C	0.0

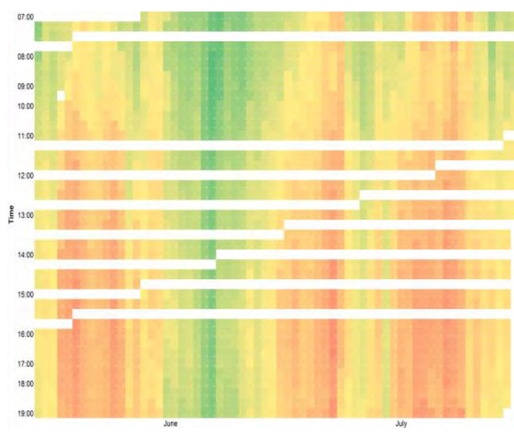


Fig. 17 Indoor air temperature plot for gallery, May to July 2015

7.3 Temperature profile

To evaluate the effectiveness of the ventilative cooling system, the internal temperature profile of the reference room has been compared with the opening automation signal and the external temperature. Figure 18 displays the temperature profile for gallery during one of the hottest period in July 2015. The graph shows that due to high external temperatures ventilative cooling operated only within short periods of time. The internal temperature of the gallery is relatively stable even without ventilative cooling in operation. Based on these results ventilative cooling has no significant influence on the internal temperature.

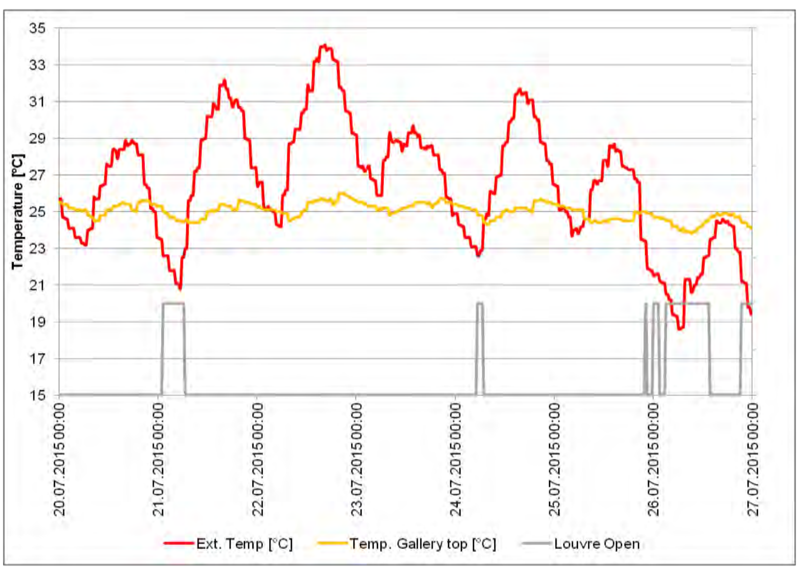


Fig. 18 Indoor air temperature profile in gallery, July 2015

7. Performance Evaluation

7.4 Tornado fans

The ventilative cooling system comprises of automated openings in combination with tornado fans. Based on the regulation parameters, the first tornado fan starts operation when the openings open. The three other tornado fans start operation gradually based on increasing internal temperature. Figure 19 displays the air flow of the four tornado fans and the opening position in July 2015. The graph shows that further optimization of control parameters is necessary, as all four tornado fans are in operation when openings are open. The electricity input for the operation of the tornado fans amounts to 1,250 kWh for June and July 2015. Based on the measured air flow and the temperature differences 314 kWh heat were discharged in June and July 2015.

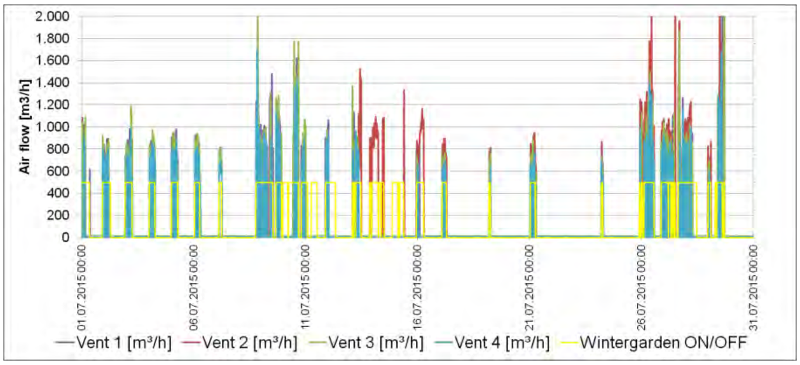


Fig. 19 AIR FLOW OF TORNADO FANS, JULY 2015

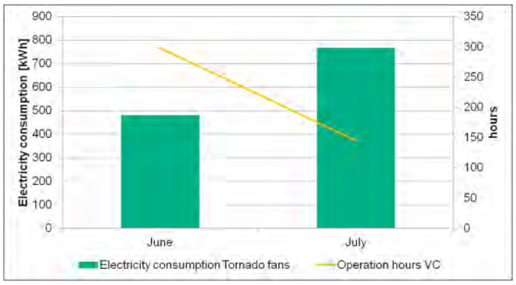


Fig. 20 ELECTRICITY CONSUMPTION OF TORNADO FANS

Table. 10 VC HOURS AND CORRESPONDING ELECTRICITY CONSUMPTION

Month	Hours of natural ventilation	Electricity consumption [kWh]
June 15	298.25	481
July 15	145	767

7.5 Occupancy profile

Typically occupancy hours are from Monday to Friday from 06:00 am until 06:30 pm, with core hours from 09:00 am to 03:00 pm. During core hours in the cooling season occupancy is on average 25 people. In the cooling season the occupation is approximately 80% of the heating season. Furthermore 1 position is occupied 24 hours 7 days a week in shift work. Data is based on the building operators information as no electronic registration system is installed.

8. Lessons Learned

8.1 Summary

The evaluation during the scope development phase was key to design an efficient tailor-made technical building system including ventilative cooling. The ventilative cooling application was integrated in the technical building system to reduce the cooling demand. Integrated design was the key for successful planning and operation of the plus-energy head quarter of Windkraft Simonsfeld AG. Monitoring data of the first summer shows that further optimization is required regarding control parameters.

8.2 Detailed list of lessons learned

Table. 12 Key Lessons Learned **Design and Construction**

Item	Lesson	Importance
1	A detailed evaluation of the building location, building structure and its operation profile during the concept phase was essential to adapt the ventilative cooling system to the building.	High
2	Design simulations are essential to proof the developed concept already during the planning phase (for example regarding required ventilation cross-sections).	High
3	Integrated design with frequent exchange within the planning team was essential to develop the most suitable technical building solution.	High

Table. 13 Key Lessons Learned **Operation / Post Occupancy**

Item	Lesson	Importance
1	A data monitoring system is essential to optimize the building performance and interaction of different technical building systems. More than one cooling/heating period is needed to optimize systems.	High
2	The monitoring data showed that the tornado fans did not operate according to the planned regulation strategy during the first operation period. Higher air flows during night in combination with lower night cooling temperature set points would allow undercooling to provide a temperature buffer.	High
3	The transported cooling energy of the ventilative cooling system was low compared to the active cooling system during the first period of operation.	Moderate
4	As external temperatures during hot periods in 2015 did not fall below 25 °C, the active cooling system is reasonable to avoid overheating.	Moderate

9. References & Key Contacts

9.1 References

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9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
Windkraft Simonsfeld AG	Client	Martin Steininger office@wksimonsfeld.at +43 2576 3324
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07_BE.1_Renson

Key Features & Climate

IEA EBC Annex 62 The IEA project on ventilative cooling

1.1 Introduction

The low-energy office building of Renson, a company that develops and manufactures ventilation and solar shading systems, was built in 2003. The office building is located in between the manufacture plant and the highway in Waregem (Belgium). The office building is designed to demonstrate the so-called ‘healthy building concept’, which relies on natural ventilation and solar shading to achieve indoor air quality and temperature control with limited energy consumption (no air circulation and refrigeration equipment).

Indoor air quality control is provided by a system consisting of self-regulating inlet vents and passive stack exhausts. Temperature control in summer is achieved by a system for natural night ventilation with motorized inlet and outlet windows.

Fig.1 Renson Office Building, Waregem, Belgium

Table.1 Key Information about building

Location	Waregem, Belgium
Building Type	Office
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Natural
Year of Completion	2002
Floor Area (m²)	2107
Shape Coefficient (%)	76
Openable Area to Floor Area Ratio (%)	2,0 (inlet) / 0,6 (outlet)
Window to Wall Ratio (%)	94
Sensible Internal Load (W/m²)	20,49
Climate Zone (KG) (words?)	Cfb
No. of Days with T_e max > 25	24
Cooling Season Humidity	Low
Heating Degree days (Kd) (T_b = 16.5°C)	2301

1.2 Local Climate

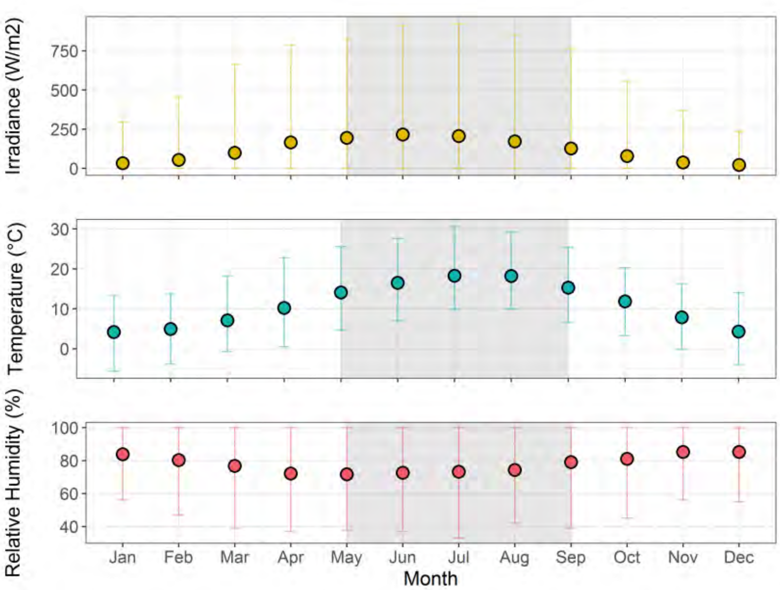


Fig.2 Mean, maximum and minimum external conditions in Waregem using TMY3 from Meteonorm 7 (cooling season shown shaded)

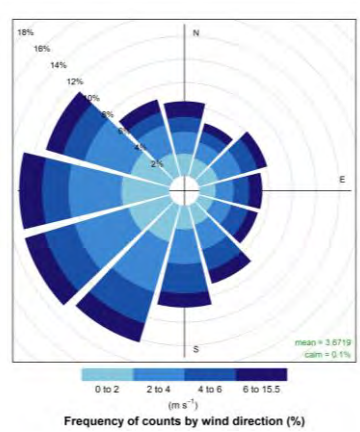


Fig.3 Wind rose for Waregem

2. Building Information

2.1 Description

All offices are located on the second floor on top of a ground and first floor with meeting and conference rooms and building services. The office floor is supported by 6m high columns, in order to hide the production plant from view. The façade is almost completely glazed. Properties of the insulating glass and other thermal building data are shown in Table 2. The floor consists of a raised (false) floor system.

Figures 1 shows a plan and section of the second floor. The office floor consists of an open plan office (n°1), oriented to the north, surrounded by small offices on the south-west side (n°2 and 3), internal (n°4) and external (n°5) meeting rooms on the south-east and north-east side and lunch rooms (n°6). With exception of the external meeting rooms (n°5), which are mechanically ventilated, all other rooms are naturally ventilated.
A prerequisite for the feasibility of any night ventilation system for temperature control is a reduced cooling load in the building. The following measures contribute to this: automated external sun blades at the south-west side, energy-efficient lighting and office equipment, a well-insulated roof and accessible thermal inertia of the concrete office ceilings (625 kg/m² thermal mass).

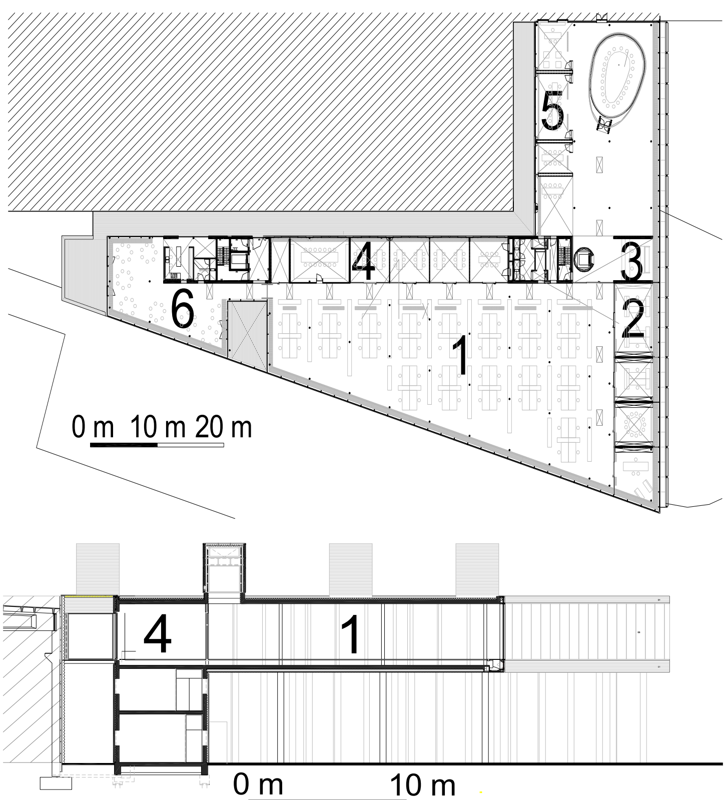


Fig 4. FLOOR PLAN (TOP) AND VERTICAL SECTION OF THE OFFICE FLOOR (BOTTOM)

Table.2 BUILDING PROPERTIES

Property	Unit	Value
Occupant density	m^2/p	21.07
Hours of occupancy	h/week	45
Sensible Internal Load	(W/m^2)	20.49
Window U-value	W/m^2K	1.3
Window g-value	(-)	0,61 (NE) 0,53 (NW)
Wall U-value	W/m^2K	0.4
Roof U-value	W/m^2K	0.3
Floor U-value	W/m^2K	0.5
Thermal Mass (ISO 13790)	-	Medium
Window to Wall Ratio	%	94
Air-tightness (@50 Pa)	1/h	-
Shape Coefficient (1/m)	%	76

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	•
Maintenance Costs	•
Energy costs	●
Solar Loads	⬤
Internal Loads	⬤
External Noise	⬤
Internal Noise Propagation	⬤
Air Pollution	●
Rain Ingress	⬤
Insect prevention	⬤
Burglary prevention	•
Privacy	•
Air Leakage	•

3. Energy Systems

A natural ventilation system is provided in the building. It consists of acoustic self-regulating inlet grills and passive stack exhausts. In the heating season, the air is heated by a gas boiler. Natural cooling is provided, except for the accounting offices: an overhead fan-coil is integrated in a false ceiling.

3.1 Heating System

The heating system consists of two condensing gas boilers (production) with natural convectors (emission), mainly located along the curtain wall. The supply air is heated by this underfloor convector heating system (see Figure 5).

Fig. 5 UNDERFLOOR CONVECTOR HEATING SYSTEM

3.2 Electrical Power Supply

Three small wind turbines (5.3m diameter blade) with a nominal power of 6.5 kW each at 10 m/s wind speed are located on the roof of the building (see Figure 6).
Figure 7 shows the annual energy consumption (natural gas for heating and electricity) of the landscaped office and the heating degree days (HDD).

Fig. 6 WIND TURBINE ON TOP OF THE BUILDING

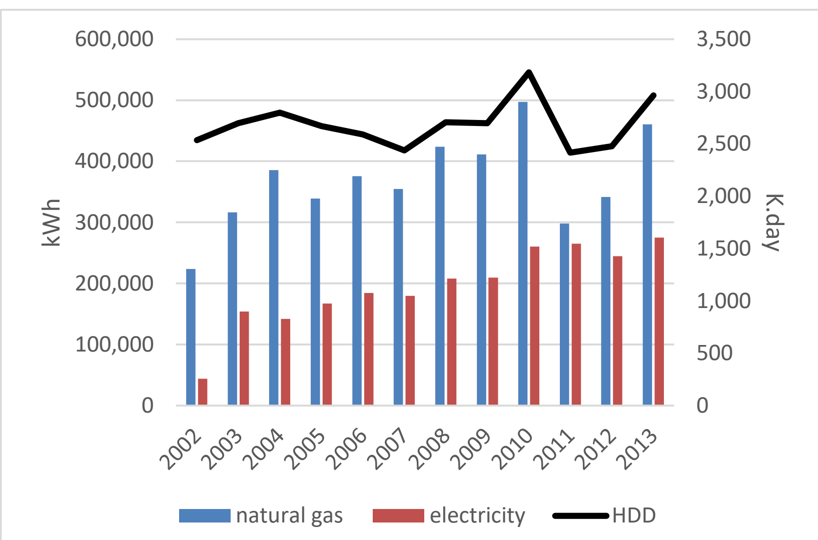


Fig. 7 ANNUAL ENERGY CONSUMPTION OF THE LANDSCAPED OFFICE

4. Ventilative Cooling

4.1 Principles

Temperature control in summer is achieved by a system for natural night ventilation (see Figure 9). Outside air enters the office floor at night through bottom hung windows, located at the bottom of the curtain wall. The air cools down the exposed concrete ceiling and leaves the building through outlet windows in chimneys on top of the building. This natural night ventilation system is primarily driven by thermally (stack) generated pressures. The height difference between supply and extraction windows is 7.5m. The openings are designed to reach a mean ventilation flow at night of 6 ach. The openable Area to Floor Area Ratio of inlet and outlet openings is 2% and 0.6%.

4.2 Components

Two type of components are integrated. Motorized bottom hung inlet windows (with a height of 0.42 m and an opening angle of 45°) are located at the bottom of the curtain walls over the full length of the façade (i.e. 142.6m) (see Figure 10).
The extractions consists of 15 chimneys on top of the building with motorized top hung windows (0.62 m x 1.90 m, opening angle of 50°) at both sides of the chimney (see Figure 8). Only one window is opened, depending on the wind direction (see control strategy).
Both components are protected by external louvres (shielding effect is included in Cd coefficient).

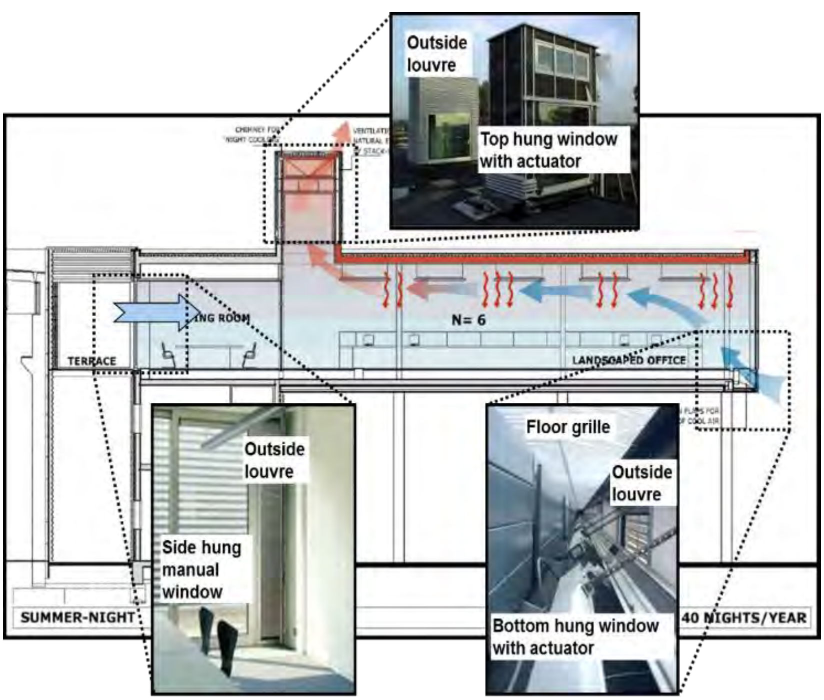


Fig. 9 NIGHT VENTILATION PRINCIPLE

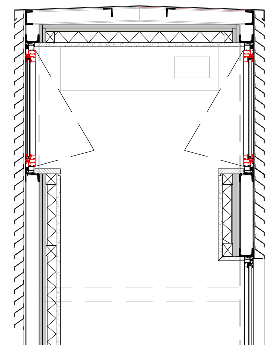


Fig. 8 CHIMNEY WITH OUTLET TOP HUNG WINDOWS

Table. 4 CAPACITY DIMENSIONING

Parameter	Value
Component ID	Inlet window
Type (As per SOTAR)	guiding
Geometric opening area (total)	42.35 m²
Discharge Coefficient (Cd)	0.25
Overall Dimensions (total)	0.42 x 142.6 m²
Porosity (A_w/A_f)	0.71
Component ID	Outlet window
Type (As per SOTAR)	guiding
Geometric opening area	0.90 m²
Discharge Coefficient (Cd)	0.23
Overall Dimensions (1 window)	0.62 x 1.90 m²
Porosity (A_w/A_f)	0.77

Fig. 10 INLET BOTTOM HUNG WINDOW AT THE BOTTOM OF THE CURTAIN WALL

5. Control Strategy

5.1 Control Strategy Overview

Both inlet and outlet windows are automatically controlled in response to the control algorithm for night ventilation. The occupants may also individually control the inlet windows if additional airing is desired.
In the chimney two windows at opposing sides are present. Depending on wind direction, the window on the leeward side will be automatically opened.

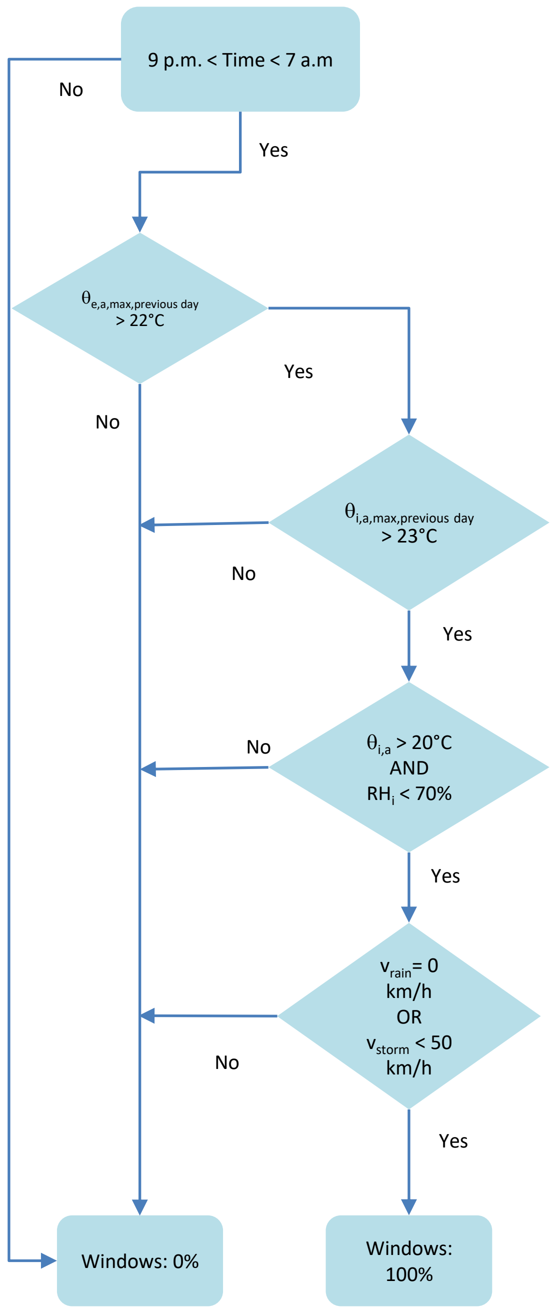


Fig. 11 CONTROL STRATEGY FLOWCHART

Table. 5 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/Target	Value
Maximum external temperature of the previous day low limit	Target	22°C
Max internal temperature of the previous day low limit	Target	23°C
Zone set point temperature	Target	20°C
Indoor relative humidity	Input	Variable
Wind speed	Input	Variable
rainfall	Input	Variable
Window position	Output	0%/100%

5.2 Control Strategy Description

The controls of the night ventilation system was initially set as follows (see Figure 11). The system operates generally from 9 p.m. till 7 a.m. The operation time may be extended in extremely warm summer periods. The operation of natural night ventilation further depends on the maximum inside and outside air temperature of the previous day ($\theta_{i,a,max} > 23°C$ and $\theta_{e,a,max} > 22°C$), on inside air temperature ($\theta_{i,a} > 20°C$) and relative humidity ($RH_i < 70\%$), wind speed during rain (no wind) and wind speed for storm ($v < 50$ km/h). When these conditions are fulfilled, the inlet and outlet windows are opened automatically.

In the first years, experiences were gathered about the control algorithm of the natural night ventilation system. Following features are added:

- Attenuations (hysteresis) on the set point temperatures in order to avoid continuous oscillation of the windows around the set point values.
- Measuring the temperature of the accessible thermal mass in the building rather than the air temperature in order to really cool the thermal mass and reduce oscillation of the windows.
- The heating system is never activated the day following a night when night cooling operated in order to avoid that the heating system shortly operates.

6. Design Simulation

6.1 Summary

Optimisation simulations were performed in the BES program CAPSOL (see http://www.physibel.be/v0n2cp.htm). 8 scenarios are compared to check if an air change rate of 6 h^{-1} would be sufficient to have an acceptable thermal summer comfort in the open plan (n° 1 on Figure 1) and corner office. Internal heat gains, airflow rate, thermal mass of floor and ceiling and cooling capacity in corner office are varied (see Table 8).

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Concept Design	CAPSOL	Overheating Risk

6.2 Simulation of overheating risk

The evaluation of overheating risk is done by checking the amount of working hours of indoor operative temperature exceeding 25°C and 28°C. Simulation period was from May 28 till June 24. Figure 13 shows the exceeding hours in the landscaped and corner office for the 8 scenarios as defined in Table 8. Following conclusions can be taken from these results. The internal heat gains in the open plan office have a major influence on the thermal comfort (scenario 1 compared to scenario 2). A cooling capacity of 8000 W in the corner office is advised (see scenario 3, 4 and 5). This capacity has to be determined in more detail in other simulations. Thermal mass of the ceiling has a larger impact on the thermal comfort than the thermal mass of the floor (scenario 7 and 8 compared to scenario 6). Scenario 6 shows the best results. Temperatures are simulated for the whole summer period (April 29 till September 29). A good thermal comfort in both offices was found, i.e. number of temperatures exceeding 25°C equals respectively 78h and 81h in the open plan and corner office, i.e. smaller than 100h. The number of hours exceeding 28°C was smaller than 20h. Figure 14 show the temperature profile in the landscaped and corner office in a warm summer week (Monday till Sunday) in scenario 6.

Table. 8 DESIGN SCENARIOS

n°	Internal heat gains (kW)	Cooling corner office	Ventilation corner office	floor	ceiling
1	26	-	-	Heavy	Heavy
2	16	-	-	Heavy	Heavy
3	16	1 kW continues	-	Heavy	Heavy
4	16	5 kW, T_{set} = 24°C	-	Heavy	Heavy
5	16	8 kW, T_{set} = 24°C	-	Heavy	Heavy
6	16	8 kW, T_{set} = 24°C	0.5 and 6 h^{-1}	Heavy	Heavy
7	16	8 kW, T_{set} = 24°C	0.5 and 6 h^{-1}	Light	Heavy
8	16	8 kW, T_{set} = 24°C	0.5 and 6 h^{-1}	Heavy	light

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	TRY Uccle
Overheating criteria	T_z < 26°C for 95% of h_{occ} T_z < 28°C for 99% of h_{occ}
Min IAQ air supply rate	0.5 h^{-1}
Cooling air supply rate	6 h^{-1}
Noise Level Rating	-

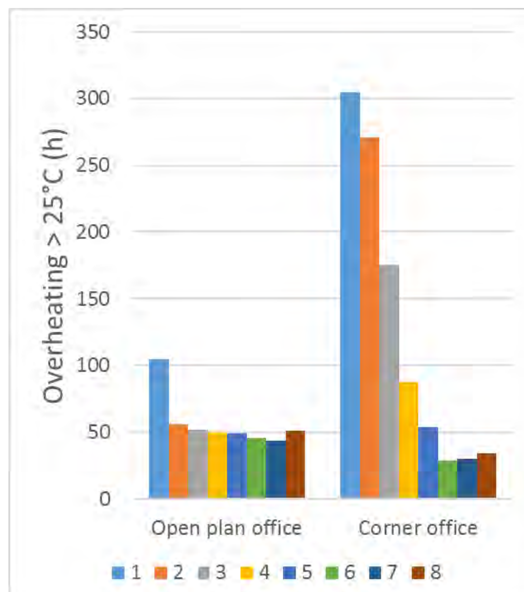


Fig. 12 HOURS EXCEEDANCE IN LANDSCAPED AND CORNER OFFICE FOR DIFFERENT SCENARIOS

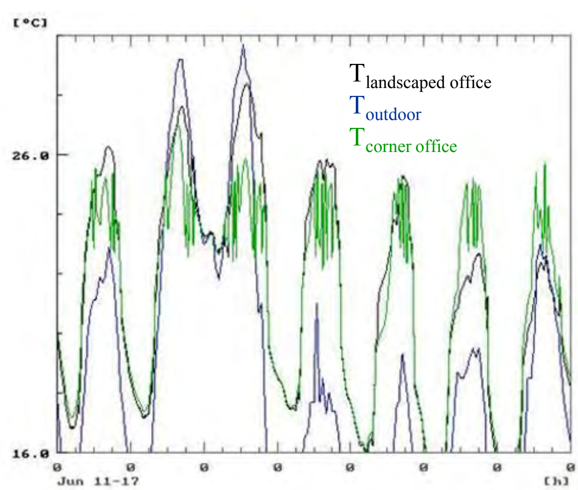


Fig. 13 TEMPERATURE PROFILE DURING WARM SUMMER WEEK IN SCENARIO 6 IN LANDSCAPED AND CORNER OFFICE

7. Performance Evaluation

7.1 Ventilation rates

Air Changes Rate (ACR) of the extraction chimney was measured in the landscaped office using a tracer gas concentration decay test method in April 2015. The used gas is SF6. Tests were completed in accordance with the procedures set out EN 12569. Figure 14 shows that the measurement setup: a small test room of 13.14 m³ underneath one of the extract chimneys. Tracer gas was injected and sampled on a height of 4m in this small room. The concentration was increased in this sealed room to a constant value of 350 ppm. After reaching this goal, the extract window and a small inlet opening (0.55 x 0.2m) were opened. The latter is an approximation and can influence the result. Table 8 presents the airflow for 1 extract chimney and the local weather conditions measured on top of the building.

Fig. 14 Test setup

Table 9 Measured airflow in an extract chimney (spring 2015)

Q (m³/s) stack	Wind velocity (m/s)	Wind direction	ΔT (°C)
0.1759	3.58	NNE	13.8
0.1907	3.76	NNE	13.1
0.1801	3.95	N	13.1
0.1866	3.43	N	12.4
0.1566	3.58	NNW	11.7

7.5 Relative humidity and IAQ

Figure 15, 16, and 17 show the ΔCO_2 concentration and relative humidity in the open plan office in July, August and September 2014. A good internal air quality (most of the time IDA-class 1 and 2) is noticed in this office.

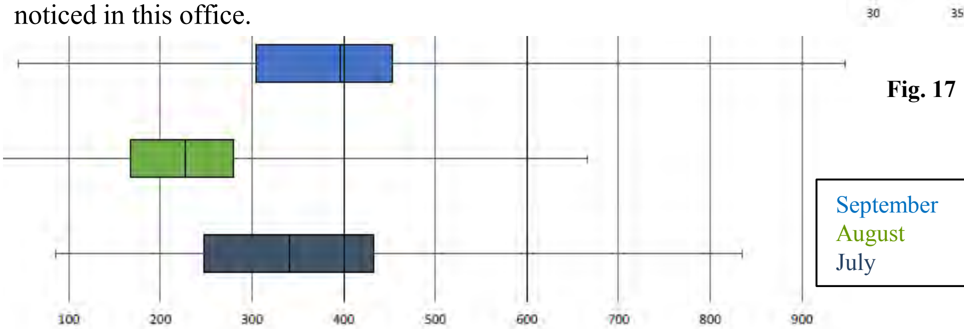


Fig. 15 ΔCO_2 in open plan office summer 2014

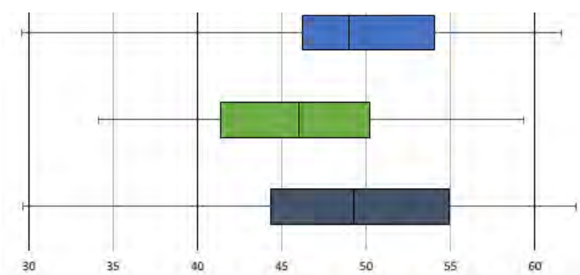
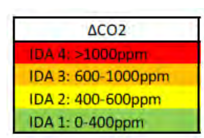


Fig. 17 Relative humidity in open plan office summer 2014



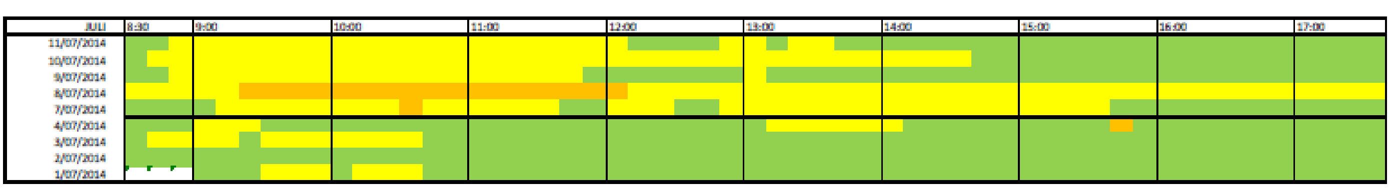


Fig. 16 Distribution of IDA-classes in open plan office July 2014

7. Performance Evaluation

7.4 Internal temperatures and thermal Comfort

Internal air temperature have been measured and recorded from 2003 in the landscaped office. Figure 18 shows the temperature exceeding hours in the landscaped office from July to September 2014. Temperature exceedings in the reception, accountancy and open plan office in 2003 are shown on Figure 20.

Figure 19 summerises the number of office hours in the open plan office exceeding 25°C to 29°C from 2003 to 2012. Table 10 provides summary data on hours of exceedance in 2003, 2011 and 2012 (i.e. warm summers in Belgium) during occupancy.

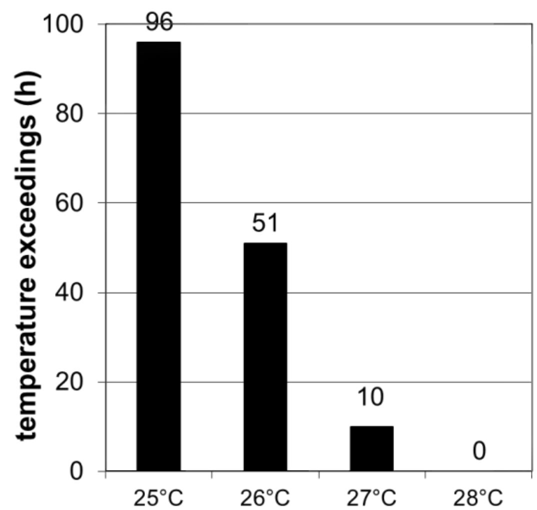


Fig. 18 TEMPERATURE EXCEEDING HOURS IN LANDSCAPE OFFICE JULY TO SEPTEMBER 2014

Table 10 PERCENTAGE HOURS EXCEEDANCE IN LANDSCAPED OFFICE

Parameter	2003	2011	2012
Total Hours > 25°C	-	-	-
Occ Hours > 25°C	7,6%	8,2%	11,4%
Total Hours > 28°C	-	-	-
Occ Hours > 28°C	1,1%	0,2%	0,3%

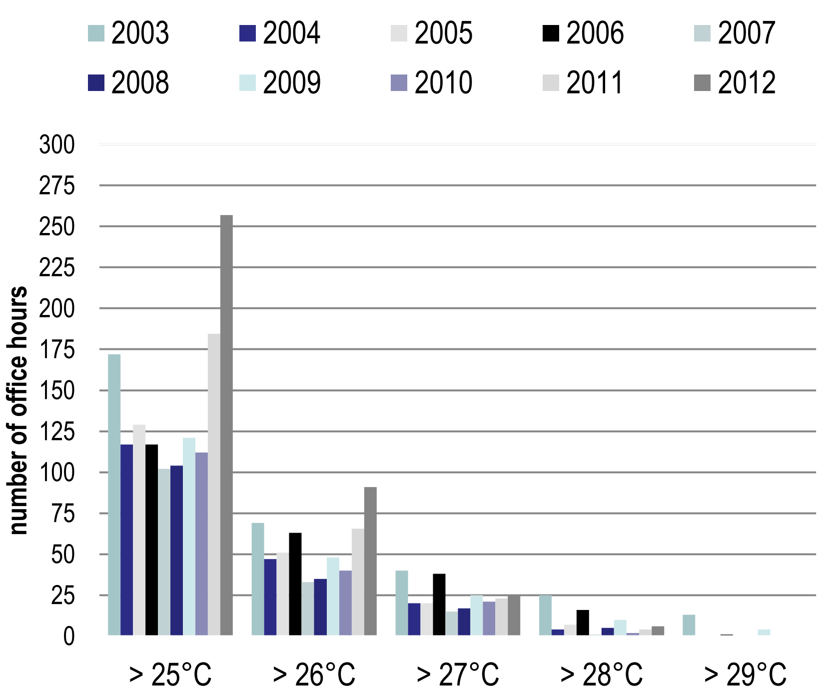


Fig. 19 EVALUATION OF THERMAL COMFORT IN OPEN PLAN OFFICE (2003 – 2012)

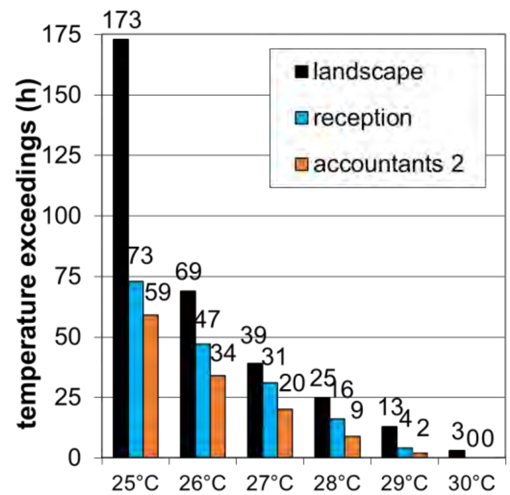


Fig. 20 TEMPERATURE EXCEEDING HOURS IN LANDSCAPE OFFICE, RECEPTION AND ACCOUNTANCY OFFICES (SUMMER 2003)

7. Performance Evaluation

7.4 Occupancy Profile

Figure 21 shows the average occupancy in the open plan office from 2003 to 2012. The occupancy is doubled in this period.

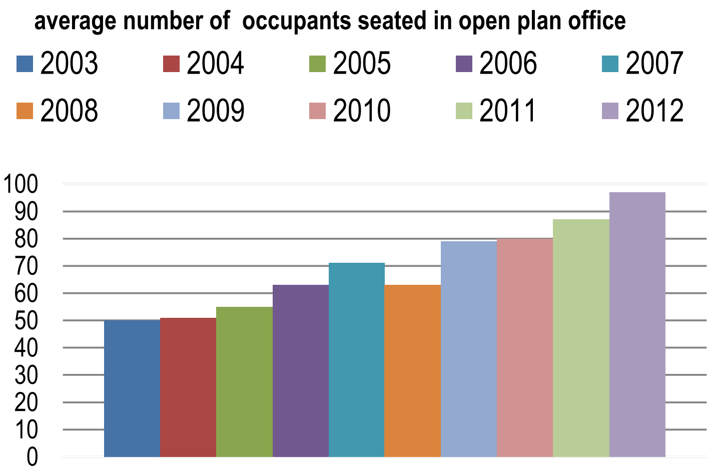


Fig. 21 AVERAGE NUMBER OF OCCUPANTS IN THE OPEN PLAN OFFICE (2003 – 2012)

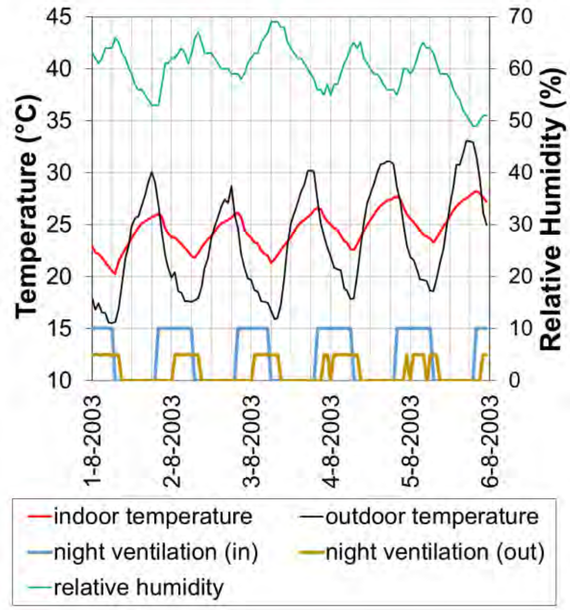


Fig. 22 MEASURED INDOOR AND OUTDOOR TEMPERATURE, INDOOR RELATIVE HUMIDITY AND OPERATION OF VENTILATION OPENINGS DURING A HEAT WAVE IN 2003

7.5 Performance of natural night ventilation

The monitoring of the effective performance of the system in summer of 2003 showed that the system was in operation every night between May 28 and August 27 and 8 days during the second half of September. Control parameters were fine-tuned in this period. Figure 22 shows temperatures, relative humidity and operation of ventilation openings during the first week of a heat wave in August. Highest relative humidity (between 60 and 70%) and lowest temperatures occurred in the morning. Inlet windows were generally opened during the whole night. Outlet windows were separately controlled and opened and closed several times a night.

The performance of the system for night ventilation has been analysed based on the achieved temperature drop overnight (between 9 p.m. and 8 a.m. the next day). Figure 23 shows the temperature drop in the landscaped office as a function of the mean indoor and outdoor temperature difference during night (from 9 p.m. till 8 a.m.). The average temperature drop in the landscaped office was 4.1°C, it varied between 3.1 and 5.1°C with a probability of 68%. The mean indoor-outdoor temperature difference during night was minimally 3°C with a probability of 0.95 in the open plan office when night ventilation was in operation.

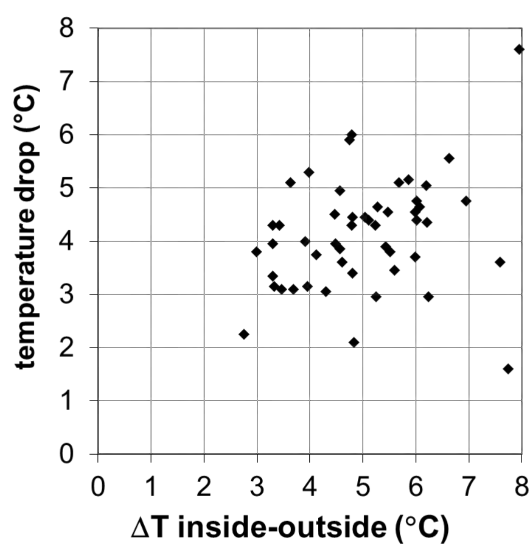


Fig. 23 TEMPERATURE DROP IN THE LANDSCAPED OFFICE

8. Lessons Learned

8.1 Summary

The Renson office building show that the requirements of good thermal comfort can be met in a moderate climate in case of a low cooling load. However, natural night ventilation does not perform well when the outdoor temperatures are extremely high. The control system has an important impact on the performances of this ventilative cooling technique. It determines the temperature drop overnight in the offices and can prevent overcooling in the morning. The building design has to be adapted to natural night ventilation: a low flow resistance between supply and extract openings is required and passive stacks need to be provided.

8.2 Detailed list of lessons learned

Table. 10 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	Dynamic simulations in the design phase are essential to test and proof the developed concept.	high
2	Frequent exchange of information within the building team (designers, constructors and research team) was essential to develop and construct the most suitable technical building solution.	high

Table. 11 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	A good thermal summer comfort and indoor air quality was measured during all the years of operation since 2003. The system is still in use after almost 15 years.	high
2	It is important to adapting the control strategy to avoid oscillation of the window opening, to maximize the cooling potential but also to prevent overcooling.	high
3	It is important to think about the maintainance in design phase. 10% of the actuators of the windows have been replaced after 15 years. It was difficult to replace the actuators in the chimneys.	high

9. References & Key Contacts

9.1 References

H. Breesch, K. Descheermaeker, A. Janssens and L. Willems (2004), "Evaluation of natural ventilation systems in a landscape office", *in 21th Conference on Passive and Low Energy Architecture*, Eindhoven, 19-22 September 2004

H. Breesch (2006) Natural night ventilation in office buildings. PhD, Ghent University

I. Pollet, P. Renson (2008) "Nightcooling: practical experiences in offices and the need for standard implementation into energy performance legislations", International journal of ventilation, vol. 6(4). p. 359-366

I. Pollet, G. Bruyneel and A. Vens (2015), "Comfort in naturally ventilated offices: in-situ measurements", in Healthy Buildings Europe 2015 conference, Eindhoven, 18-20 May, 2015

T. Claeren, S. Vandeputte (2015), "Analysis of the performances and operation of natural ventilation in the headquarters office building of Renson" (in Dutch), MSc thesis, KU Leuven Faculty of Engineering Technology, Ghent

9.1 Key Contacts

Table. 12 KEY PROJECT CONTACTS

Company	Role	Contact
Renson Ventilation nv	Client, Sun Screens and windows	Anneleen Vens Anneleen.Vens@renson.be +32 56 62 71 11
Crepain Binst Architecture	Project Architect	+32 32 13 61 61
VK Engineering	Project Engineers	DIRK SLABBINCK +32 51 26 20 20
Bekaert Building Company	Construction Contractor	+32 56 68 90 91
Chauffage Declercq	Systems Contractor	+32 51 31 18 36

1.1 Introduction

A new nZEB school building is realised at the Technology campus Ghent of KU Leuven (Belgium) on top of an existing university building. The building contains 4 zones: 2 large lecture rooms, a staircase and a technical room. The lecture rooms have a floor area of 140 m², a volume of 380 m³ and a maximum capacity of 80 students each.
The aim of this project is to realise a school building that is used as normal lecture rooms but at the same time is a test facility for research on building energy-efficiency strategies in a “real use” environment. Therefore, the 2 lecture rooms are thermally insulated from the outside, the neighbouring zones and each other. The building is designed according to the passive house standard.
The building is equipped with an all air system with balanced mechanical ventilation with a the total supply airflow of 4400 m³/h. Demand controlled ventilation with 4 VAV boxes control the airflow based on CO2-concentrations in the rooms. The building is cooled by three techniques of ventilative cooling: (1) natural night ventilation (opening the windows at both sides of the building) (2) a modular bypass in the AHU and (3) indirect evaporative cooling (IEC) with a maximum capacity of 13.1 kW.

Fig.1 Test lecture rooms of KU Leuven Technology Campus Ghent, Ghent, Belgium

Table.1 Key Information about building

Location	Ghent, Belgium
Building Type	School
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Urban
Ventilative Cooling Strategy	Hybrid ventilation
Year of Completion	2012
Floor Area (m²)	278.4
Shape Coefficient (%)	96
Openable Area to Floor Area Ratio (%)	4.0
Window to Wall Ratio (%)	26.5%
Sensible Internal Load (W/m²)	46
Climate Zone (KG) (words?)	Cfb
No. of Days with T_e max > 25	24
Cooling Season Humidity	Low
Heating Degree days (Kd)	2301 (16,5°C)

1.2 Local Climate

.

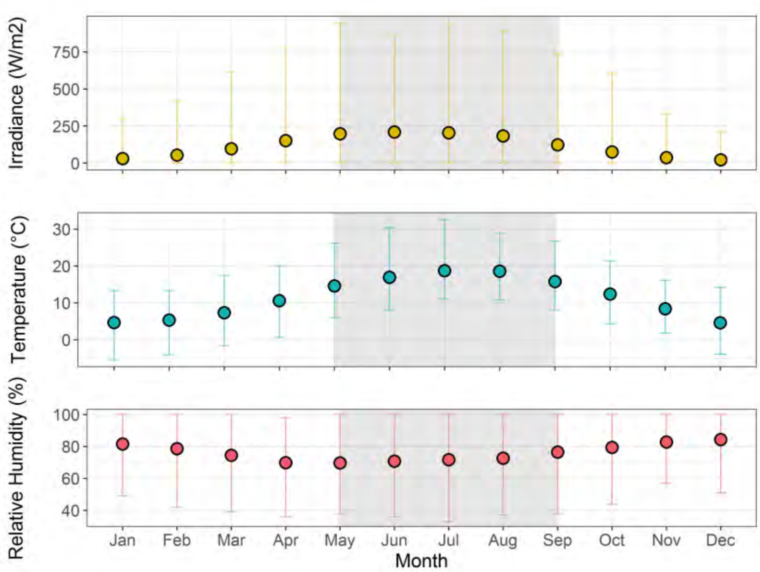


Fig.2 Mean, maximum and minimum external conditions in Ghent using TMY3 from Meteonorm 7 (cooling season shown shaded)

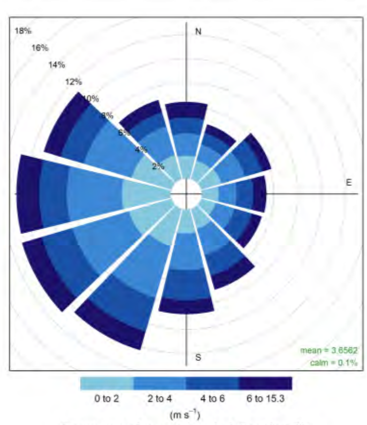


Fig.3 Wind rose for Ghent

2. Building Information

2.1 Description

The building was constructed according to the Passive House standard. There are two lecture rooms (1) and (2), a staircase (3) and a technical room above the lecture rooms (4). The lecture rooms are designed as identical zones with a different thermal mass. The lower class room has a brick external wall with exterior insulation. The upper class room has a lightweight timber frame external wall with the same U-value. Both lecture rooms have a concrete slab floor. The building is very air tight: lecture room 1 and 2 have an air tightness of 0.47 h^{-1} and 0.29 h^{-1} respectively. The windows are constructed with triple glazing and have a g-value of 0.52 The window-to-wall ratio is 27% in the northwest façade and 26% in the northeast façade. The window-to-floor ratio is 13%. The windows are provided of internal and external solar shading. The external solar shading are moveable screens on the southwest façade which are controlled automatically and provided of manual overrule.

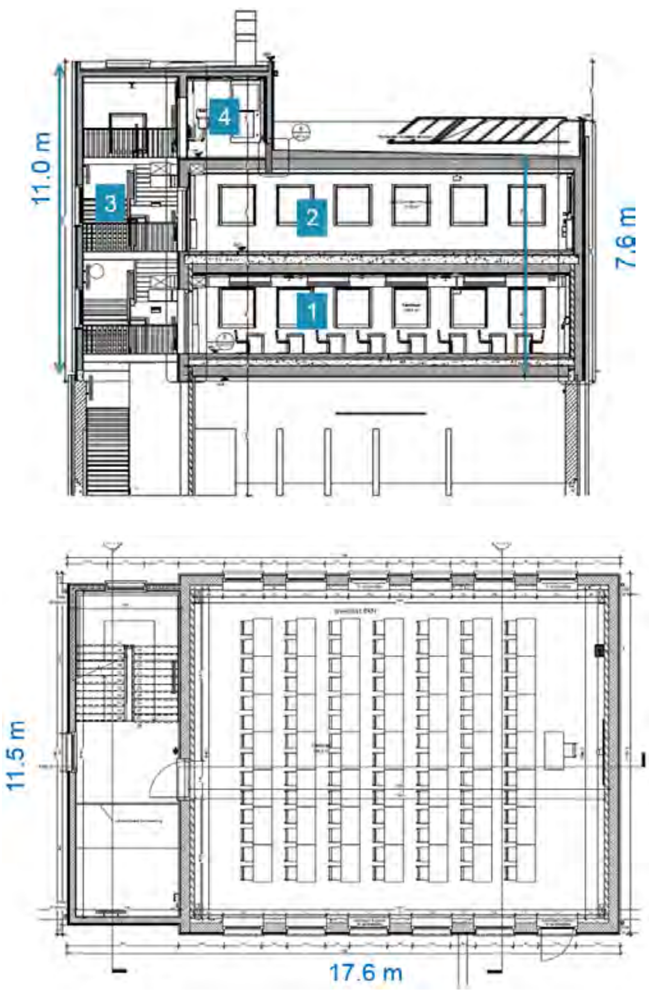


Fig 4. Top image is the section of the two lecture rooms. Bottom figure is the floor plan of one lecture room.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	1.78
Hours of occupancy	h/week	30
Sensible Internal Load	(W/m^2)	46
Window U-value	W/m^2K	0.65
Window g-value	(-)	0.52
Wall U-value	W/m^2K	0.15
Roof U-value	W/m^2K	0.14
Floor U-value	W/m^2K	0.15
Q-value (from Japan)	(W/ m^2)/K	0.45
Thermal Mass (ISO 13790)	-	Medium (1^{st}) Light (2^{nd})
Window to Wall Ratio	%	27% (SW) 26% (NE)
Air-tightness (@50 Pa)	1/h	0.41 (1st) 0.29 (2nd)
Shape Coefficient (1/m)	%	96

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	•
Energy costs	●
Solar Loads	●
Internal Loads	●
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	●

3. Energy Systems

An all air system with balanced mechanical ventilation is installed for ventilation, heating and indirect adiabatic cooling (IEC).

3.1 Heating System

For heating purposes, the air is preheated by air-to-air heat recovery, i.e. two cross flow plate heat exchangers connected in series, with an efficiency of 78%. Additionally, heating coils of 7.9 kW each are integrated in the supply ducts in each lecture room.
The heating production system consists of a condensing wood pellet boiler with an internal storage of 600 l. The maximum heating power is 8 kW and the maximum efficiency is 106 %.

3.2 Electrical Power Supply

Electrical power is supplied by the grid.

Fig. 5 WOOD PELLET BOILER

Fig. 7 HEATING COILS IN THE AIR HANDLING UNIT

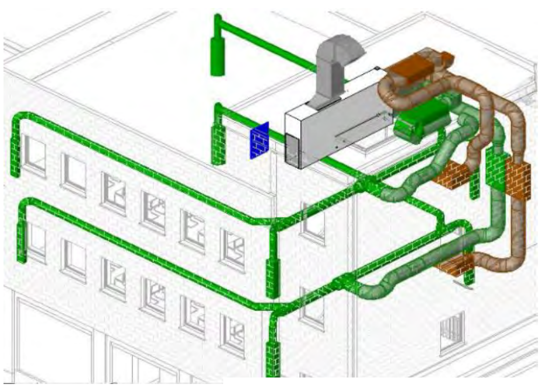


Fig. 6 VISUALISATION OF AIR DISTRIBUTION (SUPPLY IN GREEN, RETURN IN BROWN)

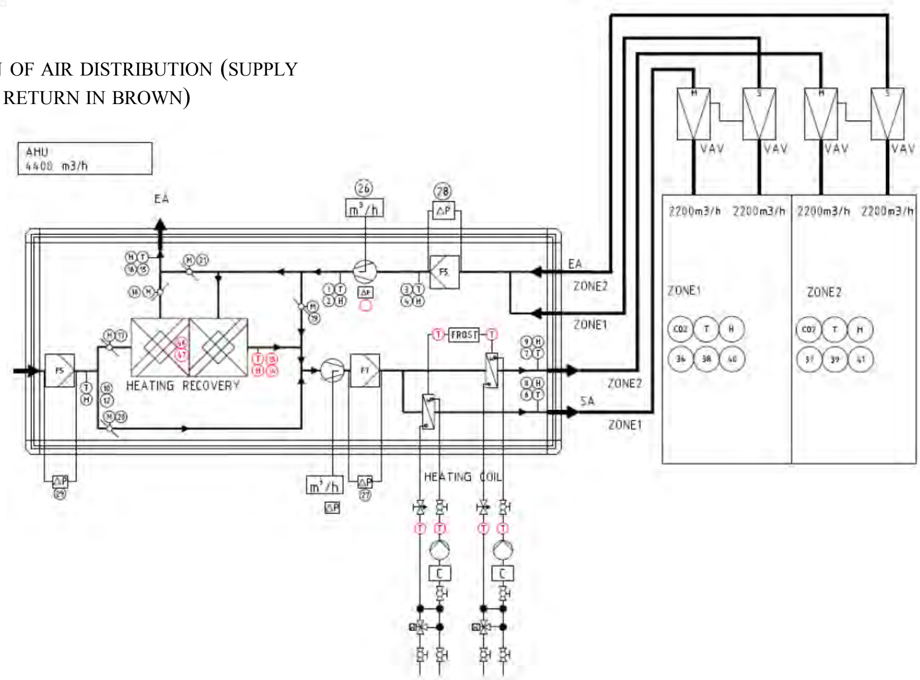


Fig.8 TECHNICAL DRAWING OF VENTILATION INCLUDING HEATING

4. Ventilative Cooling

4.1 Principles

Three different principles of ventilative cooling are implemented in this building: (1) natural night ventilation, (2) a modular bypass in the air handling unit and (3) indirect evaporative cooling (IEC).

Night ventilation relies on cross ventilation through openable windows at both sides of the room (see Figure 9).

The operaton of the bypass and the IEC are visualized in Figure 10. The exhaust air is evaporized, so the fresh air is cooled through the heat exchanger in an adiabatic process. As a result, the supply temperature is cooled to a temperature lower than the outdoor air temperature.

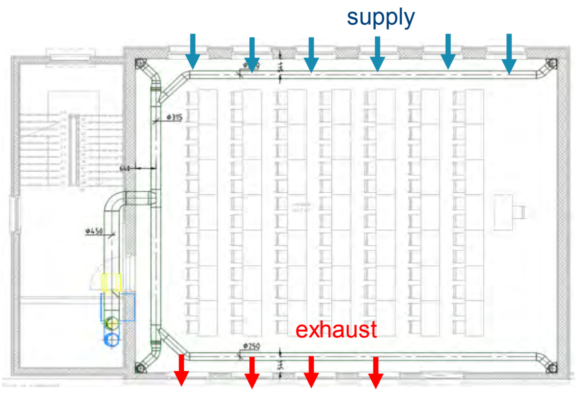


Fig. 9 PRINCIPLE OF NATURAL NIGHT VENTILATION

4.2 Components

Natural night ventilation includes 10 motorized bottom hung windows (1.29 x 1.38 m², maximum opening angle of 8.8°) with a chain actuator (see figure 11) for supply and exhaust. There are 6 windows on the southwestern side and 4 on the northeastern side of the lecture room The total effective opening area of these windows is 4.0% of the floor area.

The modular bypass and IEC are part of the AHU. The maximum airflow rate is 4400 m³/h. The maximum capacity of IEC at maximum airflow is 13.1 kW.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Component ID	Bottom hung window
Type (As per SOTAR)	guiding
Geometric opening area (total)	5.64 m²
Discharge Coefficient (Cd)	-
Overall Dimensions (total)	17.80 m²
Porosity (A_w/A_f)	0,32
Q (@ Vel = / ΔP =)	-

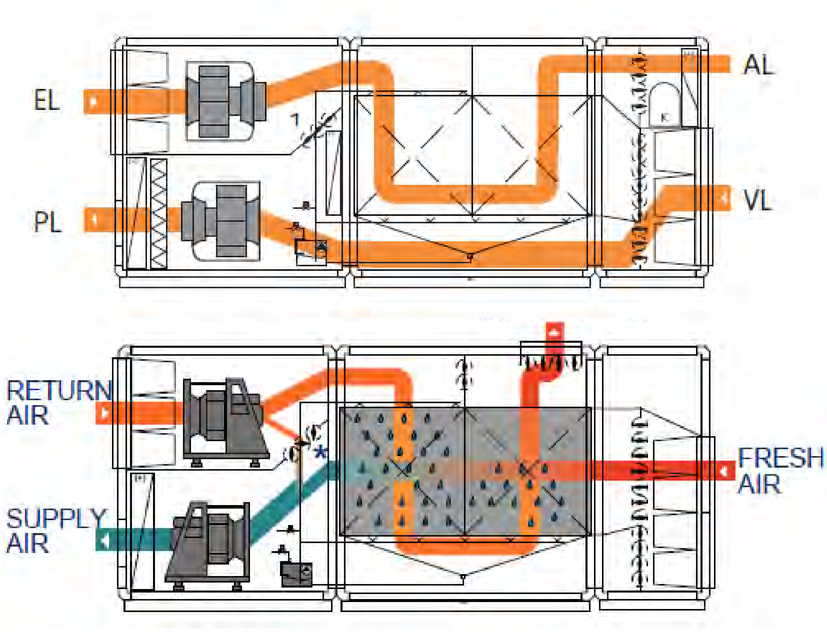


Fig. 10 SCHEME OF MODULAR BYPASS AND INDIRECT EVAPORATIVE COOLING

Fig. 11 DETAIL OF MOTORIZED WINDOW

5. Control Strategy

5.1 Control Strategy Overview

Control strategy consists of two parts. First, the control strategy of the mechanical ventilation system during occupancy is based on internal and external temperature (figure 12). This strategy actuates the supply air temperature and the flow rate.
Second, control strategy at night that actuates the windows is based on internal temperature and external weather conditions (figure 13).

Table. 5 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/Target	Value
Zone Temperature, relative humidity	Input	Variable
External Temperature, wind speed, rainfall	Input	Variable
Time, date	Input	Variable
Zone set point Temperature	Target	22°C
Supply Temperature low limit	Target	14°C
Bypass	Output	0-100%
Indirect Evaporative Cooling (IEC)	Output	0%/100%
Zone Temperature low limit	Target	22°C
External Temperature low limit	Target	12°C
Window Position	Output	0%/100%

5.2 Control Strategy Description

1. Control strategy of AHU during occupancy

The internal room temperature set point is 22°C. When the room temperature exceeds the set point + 4°C, the evaporative cooling is activated on maximum airflow rate. IEC is active until the room temperature is lower or equal to the set point – 0.5°C.
When the external air temperature is higher than 22°C, indirect evaporative cooling is activated. If the external temperature is between 16°C and 22°C, the bypass on the heat exchanger is active. When the external temperature is between 14°C and 16°C, 50% of the fresh air is sent through the heat exchanger and 50% is bypassed. When the outside air is colder than 14°C, the bypass is switched off.

2. Control strategy of natural night ventilation

Night ventilation is activated between 10.00 P.M. – 6.00 AM when the criteria below are fulfilled:

- April 1st < day of the year < October 31st
- Maximum zone temperature of the previous day > 23°C
- Zone temperature > heating set point = 22°C
- Zone temperature > outside air temperature + 2°C
- Outside air temperature > 12°C
- Internal relative humidity < 70%
- No rainfall
- Wind velocity < 10 m/s
- Windows remain open/closed at least 15 min

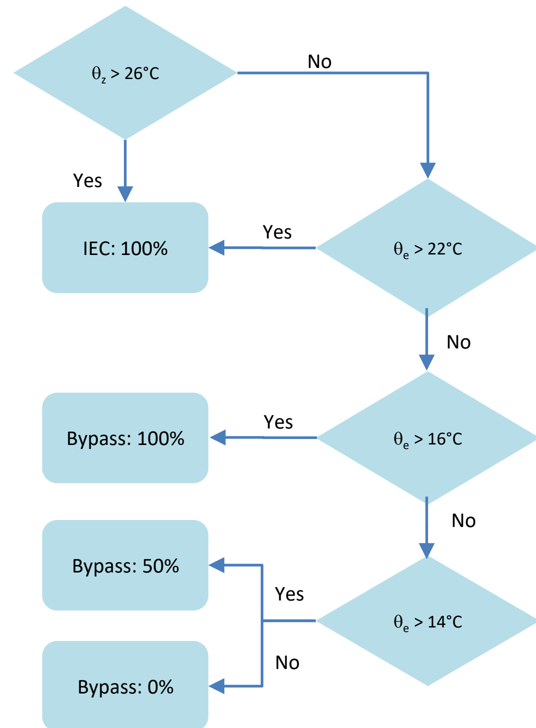


Fig. 12 CONTROL STRATEGY FLOWCHART AHU DURING OCCUPANCY

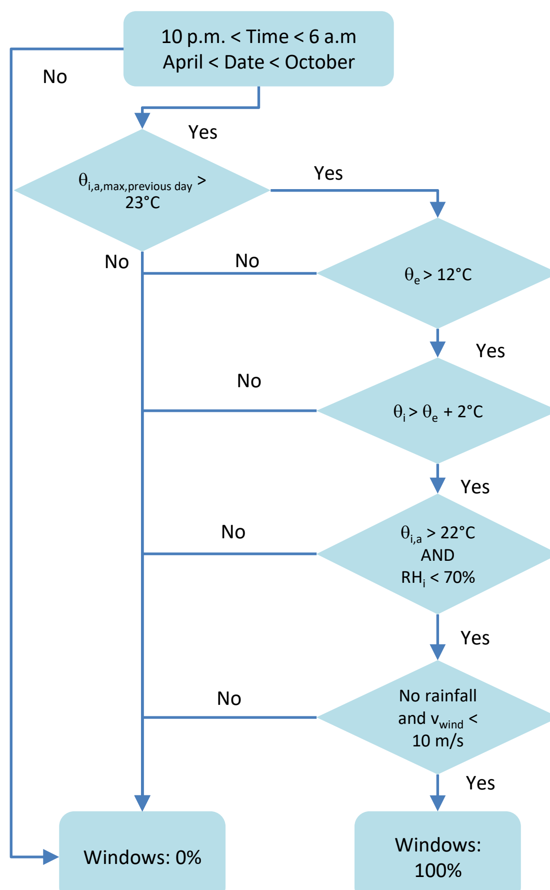


Fig. 13 CONTROL STRATEGY NATURAL NIGHT VENTILATION

6. Design Simulation

6.1 Summary

As part of the design scope, various tools were used at different stages to evaluate different performances. BES (TRSNSYS 17) is used to investigate the overheating risk and to decide which ventilation cooling strategies were needed to guarantee good thermal summer comfort in the lecture rooms. The net energy demand for heating and cooling of this school building design are evaluated by the quasi-steady state calculation method PHPP 2007 adapted for school buildings, based on EN 13790, to evaluate the energy performance of the building.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Detailed Design	TRNSYS 17	Overheating risk, Internal temperature
Construction Design	PHPP	Energy Performance

Table. 7 DESIGN CRITERIA

Parameter	Value
T_z , Summer Operative Temp	25°C
Overheating criteria	T_z < 26°C for 95 % hr_{occ}
Min IAQ air supply rate	22 m³/h.pers
Cooling air supply rate	27.5 m³/h.pers
Noise Level Rating	-

6.2 Simulation of overheating risk and net cooling demand

The overheating risk and the net cooling demand, including the effect of night ventilation, is evaluated in both lecture rooms. The amount of hours exceeding 26°C (in % of the time in use) is shown in Figure 14. As expected, without night ventilation, none of the lecture rooms meets the requirement of overheating hours less than 5% of the time in use according to EN 15251. In addition, a significant impact of night ventilation (with an ACH of 5 h^{-1}) on the overheating hours and the net cooling demand (see Figure 15) is depicted.
However, the requirement for good thermal summer comfort is not fulfilled in the lecture room on the second floor. In addition, Figure 16 shows the indoor temperatures in both rooms during a warm week in June. Thermal comfort is reasonable but not excellent. This means that additional (ventilative) cooling is needed to reach a good level of thermal comfort in summer, spring and autumn in both lecture rooms. It was decided to add IEC.

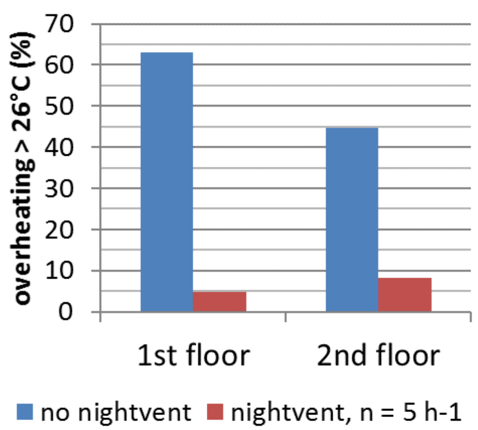


Fig. 14 PREDICTED OVERHEATING RISK

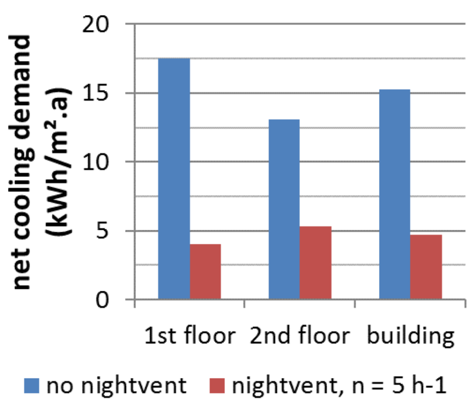


Fig. 15 PREDICTED NET COOLING DEMAND

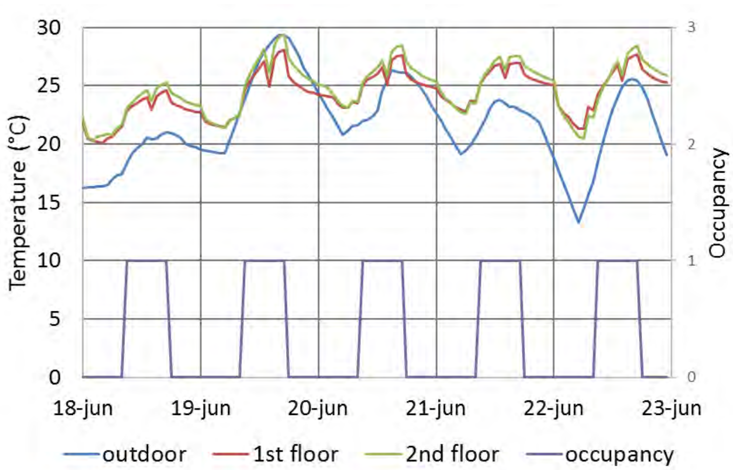


Fig. 16 INDOOR TEMPERATURES WITH NIGHT VENTILATION

7. Performance Evaluation

7.1 Ventilation Rates

Air Changes Rates (ACR) are measured at the building using a tracer gas concentration decay test method in March and April 2017. The used gas is N_2O also known as laughing gas. Tests were completed in accordance with the procedures set out EN 12569. Figure 17 shows that the measurements were carried out in a representive zone with two opposing windows with a width of 3,04m. Tracer gas was injected and sampled in the middle of this small room (see Figure 17). The concentration was increased in this sealed room to a constant value of 200 ppm. After reaching this goal, one or two windows were opened. Table 8 presents the results for single sided and cross ventilation including the local weather conditions measured on top of the building. For the cross ventilation, the 95% confidence interval for ACR is between 2,17 and 4,64 h^{-1}.

ACR were also estimated from air velocity measurements near the windows. Figure 18 shows the test set up: air velocity is measured every 10s during 30min on 4 locations with accurate omnidirectional sensors. Figure 19 presents the boxplots of the measured air velocity in case of cross ventilation. A good agreement with the results from the tracer gas decay method was found. Further details can be found in (Decrock and Vanvalckenborgh, 2017).

The air flow pattern was visualised by measuring air temperatures at different heights and positions (see Decrock and Vanvalckenborgh, 2017). Figure 20 shows the air temperatures at the start and 60 min after opening the window. The stratification at the start changes to a more uniform air distribution after 60 min.

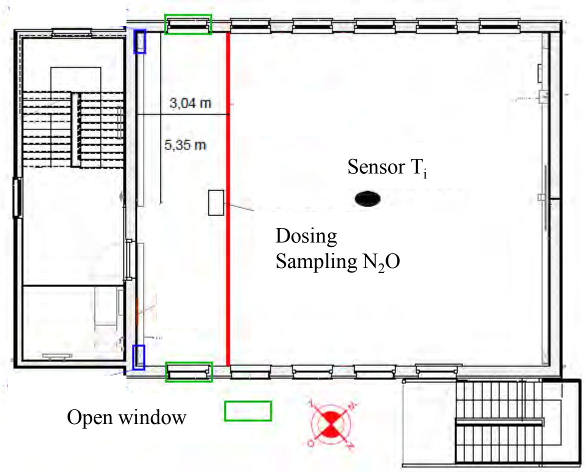


Fig. 17 Test set up tracer gas measurement

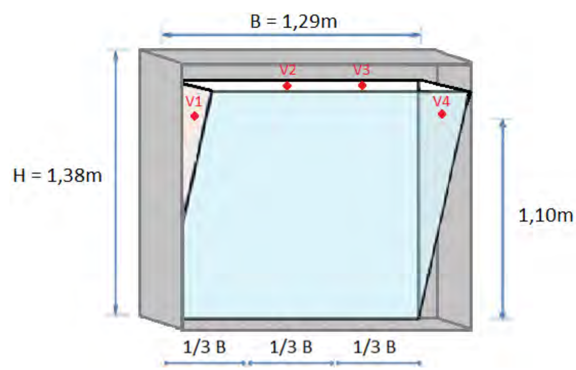


Fig. 18 Test set up and air velocity measurement (position of the sensors)

Table 8 MEASURED ACR DURING SPRING 2017

Ventilation mode	ACR (h^{-1})	Wind velocity (m/s)	Wind direction	ΔT (°C)
Cross ventilation	4,18 ± 0,42	1,9	WNW	4,3
Cross ventilation	3,76 ± 0,38	2,1	ESE	1,6
Cross ventilation	3,04 ± 0,30	2,2	ESE	2,4
Single sided	2,05 ± 0,21	2,3	SSW	-
Single sided	2,00 ± 0,20	2,68	S	-
Single sided	1,17 ± 0,12	1,45	SSW	5,1
Single sided	1,56 ± 0,16	1,78	S	8,6

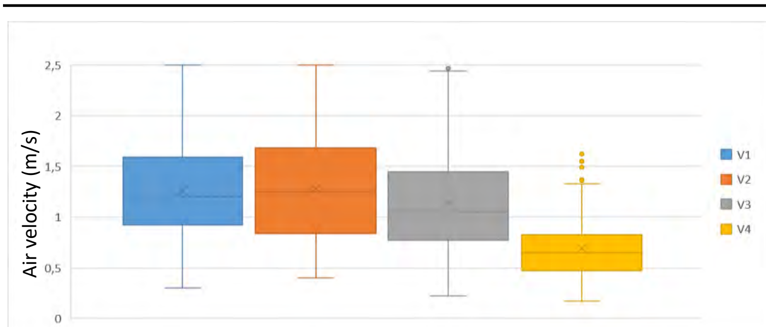


Fig. 19 Air velocity measurements for cross ventilation

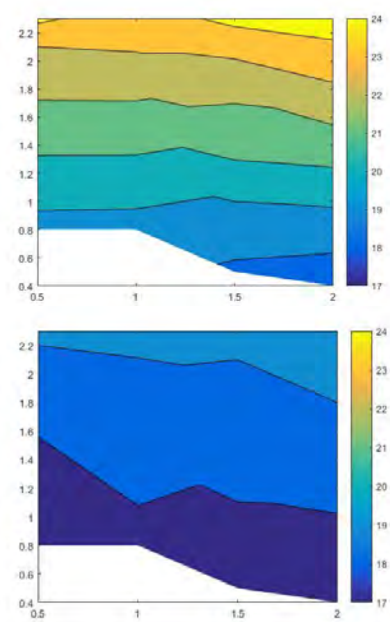


Fig. 20 air temperature profile in the room at the start (above) and after 60 min for cross ventilation

7. Performance Evaluation

7.2 Internal Temperatures

Internal air temperature have been measured and recorded during the cooling season in 2017 in the lecture room on the first floor. Figure 21 and 22 show the internal temperature and the operation of the windows for night ventilation respectively indirect evaporative cooling during extremely warm days in June 2017. In that period, IEC operates the whole day and can lower the supply temperature significantly.
Figure 23 and Table 9 present the ratio of operation time of the windows to the possible total opening hours by night (22h tot 6h) and the ratio of the operation of the IEC to the operation hours of the AHU by day.

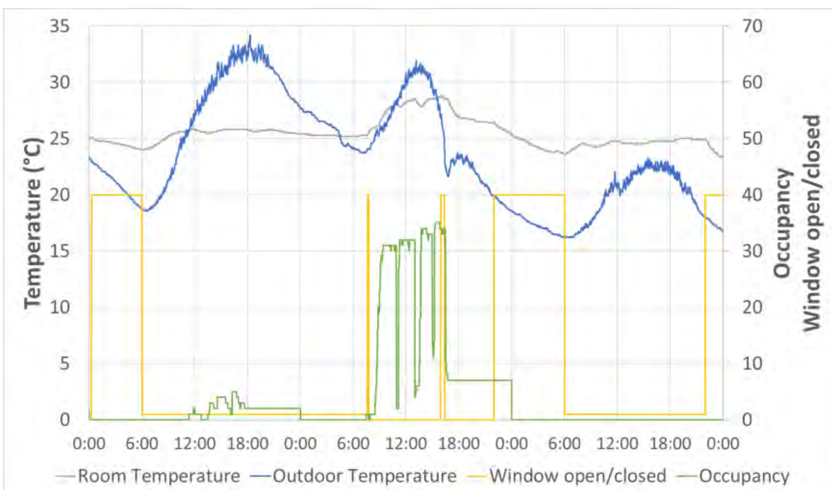


Fig. 21 INDOOR TEMPERATURE AND OPERATION WINDOWS DURING AN EXTREMELY WARM PERIOD 21-23 JUNE 2017

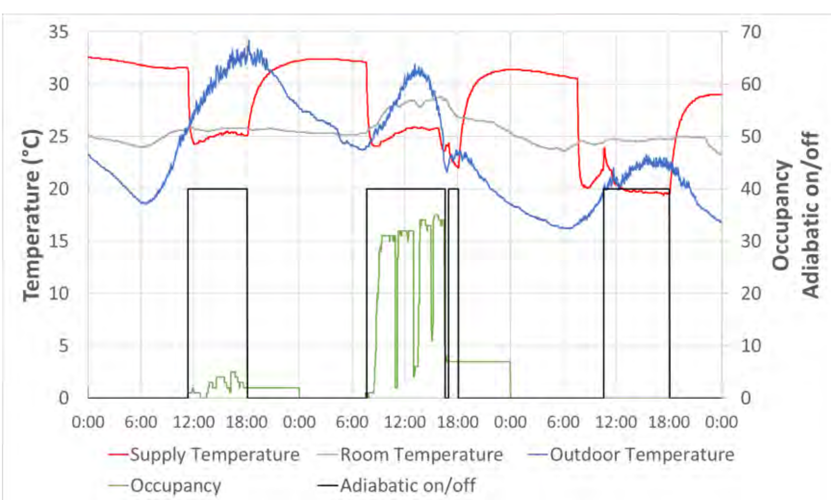


Fig. 22 OPERATION INDIRECT EVAPORATIVE COOLING DURING AN EXTREMELY WARM PERIOD 21-23 JUNE 2017

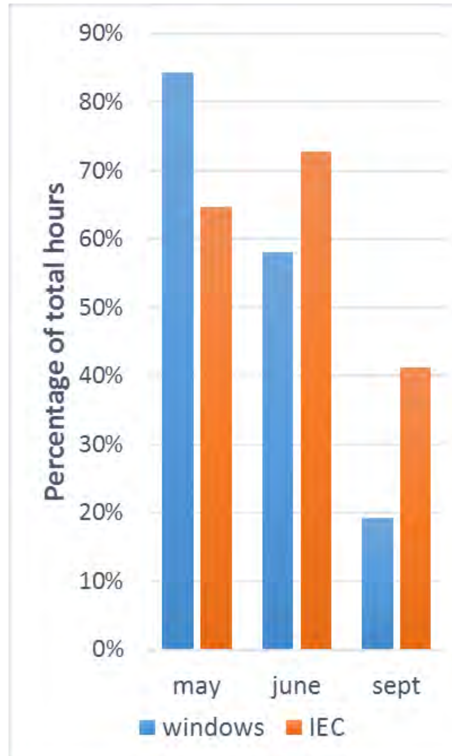


Fig. 23 PERCENTAGE OF HOURS OF OPERATION OF WINDOWS BY NIGHT AND IEC BY DAY FROM MAY TO SEPTEMBER 2017

Table 9 PERCENTAGE TOTAL HOURS OF OPERATION OF VENTILATIVE COOLING 2017

Parameter	2017
Window opening at night	45.3 %
Operation of IEC	66.1%

7. Performance Evaluation

7.3 Thermal comfort

Thermal comfort is evaluated in the lecture room on the first floor from May 22th to September 30th 2017. As there was no occupancy in July and only limited in August (see also 7.4 Occupancy profile), these months are excluded from the analysis. The number of occupied hours of exceedance of a particular indoor temperature above a threshold value is commonly taken as an overheating performance indicator. Table 10 provides summary data on hours of exceedance in 2017 during operation of the AHU. Figure 24 presents hourly indoor operative temperature in this lecture room. The percentage of hours of exceedance per month above 23°C, 25°C and 28°C are shown.

Figure 25 shows the minimum and maximum indoor operative temperature during operation of the AHU in function of the running mean outdoor temperature as defined by the Dutch adaptive temperature limits indicator. Summer and hot summer period are indicated on Figure 20.

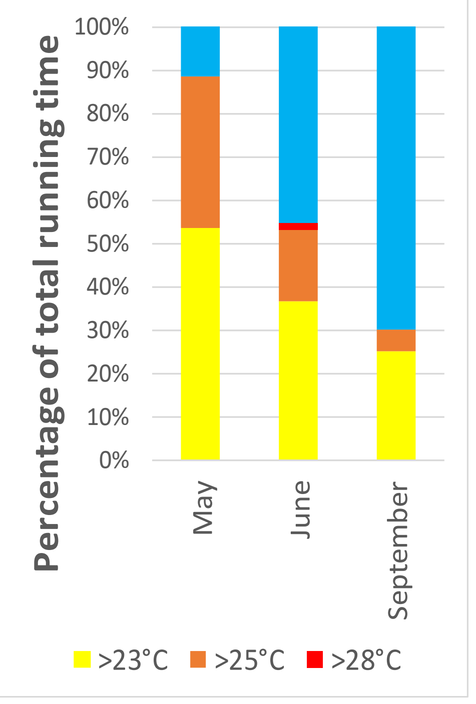


Fig. 24 Percentage of hours above threshold values for internal temperatures in lecture room on 1st floor May-September 2017

Table 10 Percentage hours exceedance

Parameter	2017
Total Hours > 25°C	5.1%
Total Hours > 28°C	0.3%

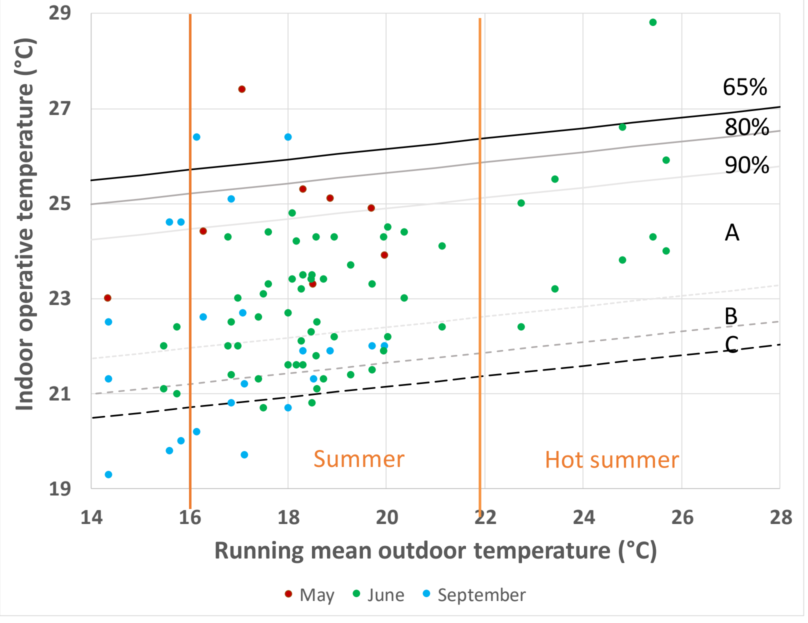


Fig. 25 Evaluation Adaptive Temperature Limits Method

7.4 Occupancy Profile

The occupancy level in the building is dependent on the academic year, which counts 124 days with courses and 63 days with exams (in January, June and August-September). Holiday periods are in April (2 weeks), July and the first half of August (6 weeks) and December-January (2 weeks).

The lecture rooms are in use from Monday to Friday between 8h15 and 18h with a maximum occupancy of 80 persons. Figure 26 shows details of 1 typical week of occupancy. There is no difference in occupancy profile between heating and cooling season.

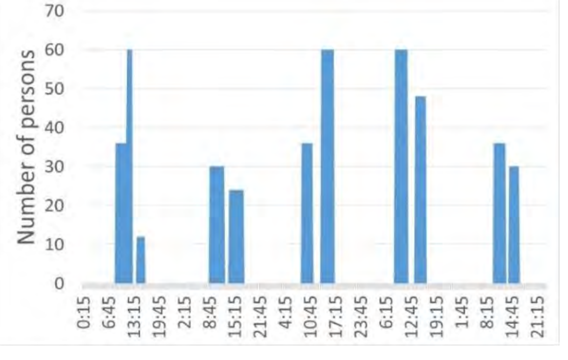


Fig. 26 Typical occupancy profile during one course week (Monday to Friday)

8. Lessons Learned

8.1 Summary

A good thermal summer comfort was measured in the test lecture rooms at the Technology campus Ghent of KU Leuven (Belgium). Only during heat waves and/or periods with high occupancy rates, high indoor temperatures are monitored.
The extensive data monitoring system was of great value to detect malfunctions, improve the control of the building systems and optimize the whole building performance.

8.2 Detailed list of lessons learned

Table. 11 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	Dynamic simulations in the design phase are essential to test and proof the developed concept. Due to high occupancy rate	high
2	Frequent exchange of information within the building team (designers, constructors and research team) was essential to develop and construct the most suitable technical building solution.	high
3	Design and construction of openable windows that are also airtight (when closed) needs particular attention.	moderate

Table. 12 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	A good thermal summer comfort and indoor air quality was measured. Only during heat waves or periods with high occupancy rates, high indoor temperatures are monitored.	
2	A data monitoring system is essential to optimize the building performance and interaction of different technical building systems. Monitoring showed e.g. that the windows for night ventilation opened and closed a lot at night during the first weeks. This was due to (1) bad translation of the signal of the rain sensor and (2) peaks in the wind velocity. These parameters are part of the control of the windows. This malfunctioning was discovered and solved by monitoring and analysing the monitoring results.	High
3	Do not forget the habits of the user and educate/inform the user. A lot of different teachers give classes in these lecture rooms. They are not used to automated blinds, ventilation and ventilative cooling. They open the door to the corridor and the windows even when it is warm outside. They have to be informed about the operation of the automated system.	High

9. References & Key Contacts

9.1 References

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R. Andriamamonjy and R. Klein (2015), "A modular, open system for testing ventilation and cooling strategies in extremely low energy lecture rooms", *in 36th AIVC Conference*, Madrid, 22-23 September 2015

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B. Merema, M. Delwati, M. Sourbron, H. Breesch (2017) "Calibration of a BES model of an educational building with demand controlled ventilation", Building Simulation 2017, *15th International IBPSA conference*, San Francisco, 7-9 August 2017

9.2 Key Contacts

Table. 13 KEY PROJECT CONTACTS

Company	Role	Contact
KU Leuven	Project Architects	Alexis Versele alexis.versele@kuleuven.be +32 495 28 80 00 Marnik.Devos Marnik.Devos@odisee.be
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Witas bvba	Engineering Office HVAC	Wim Tas info@witas.be +32 9 348 53 62
Genisol nv	Main Constructor Contractor	François Goubau francoisgoubau@genisol.be +32 475 49 60 54
Zaman Yves & co nv	Installer HVAC	Benny De Bruyn bdb.zaman@zamangroep.be +32 498 91 72 02
Menerga nv	Ventilation system	Johan Van Woensel johan.vanWoensel@menerga.be +32 495 12 03 71

09_FR_MAL

Key Features & Climate

1.1 Introduction

Maison Air et Lumière (MAL) is a modern house with a pinch of traditional French architecture built in 2011 in a beautiful area south of Paris, as part of the Model Home 2020 project. The Model Home 2020 project was launched back in 2008 with a vision for climate-neutral buildings with high livability levels and no environmental impact while focusing on the living conditions of the residents. Maison Air et Lumière complies with the Active House principles, integrating energy, indoor comfort and the environment in the building design. The modular architectural concept pays tribute to the country's cultural heritage with its distinctive pitched roof. In a modern context, pitched roofs - which in France vary in steepness according to region and climate - can be adapted to meet light and solar gain needs, as well as allowing for varied interiors to suit personal preferences.

The house combines three modules that fit together to create a visually diverse, dynamic 130 m² space that extends over one and a half storeys, with all areas under the roof put to full use.

The home's hybrid natural/mechanical ventilation system adjusts according to the temperature and weather conditions. This means that despite the region's warm summers, Maison Air et Lumière does not require air conditioning.

Fig.1 SINGLE-FAMILY ACTIVE HOUSE IN FRANCE

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Verrières-le-Buisson, France
Building Type	Single family house
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Suburban
Ventilative Cooling Strategy	Natural
Year of Completion	2011
Floor Area (m²)	173
Shape Coefficient (%)	75
Openable Area to Floor Area Ratio (%)	2.76
Window to Wall Ratio (%)	31.2
Sensible Internal Load (W/m²)	3,45
Climate Zone (KG) (words?)	Cfb
No. of Days with T_e max > 25	643
Cooling Season Humidity	~ 70%
Heating Degree days (Kd)	2939

1.2 Local Climate

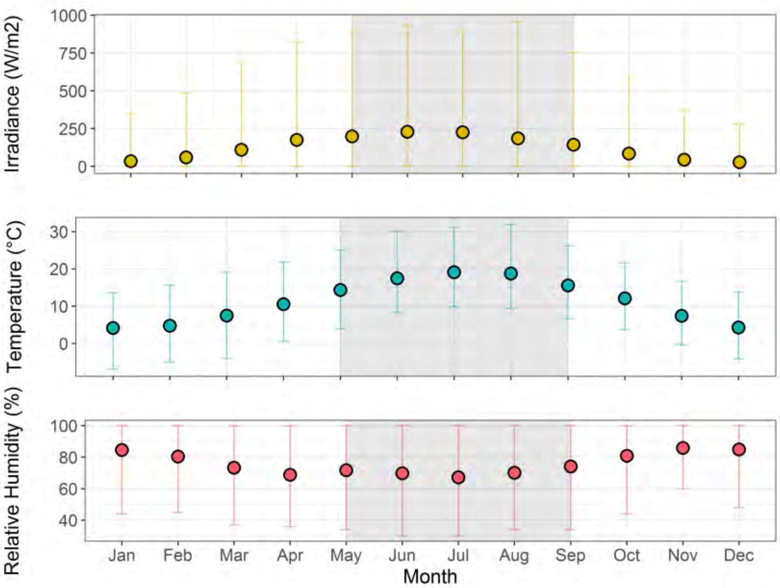

Fig.2 MEAN EXTERNAL CONDITIONS IN TRAPPES, FRANCE USING A TMY3 (SHADED AREA IN GREY INDICATES COOLING SEASON)

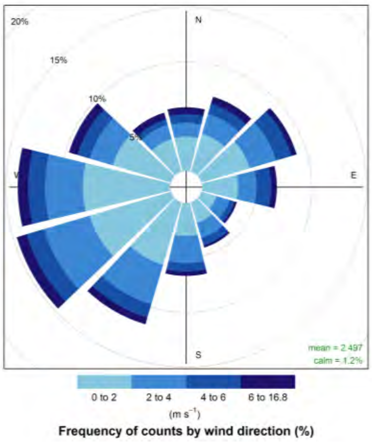

Fig.3 WIND ROSE FOR TRAPPES

2. Building Information

2.1 Description

Maison Air et Lumière's architecture is adapted harmoniously to its site and revolves around natural light and ventilation. Carefully positioned façade and roof windows bring in fresh air and sunlight from all directions to create an ideal environment and bathe the interior with a balanced, natural glow. Furthermore, the home's unique and flexible design concept enables various compositions - whether the house is small or large, in town or in the countryside. The design allows the principles of comfortable living, energy efficiency and environmental quality to easily be applied in different contexts.

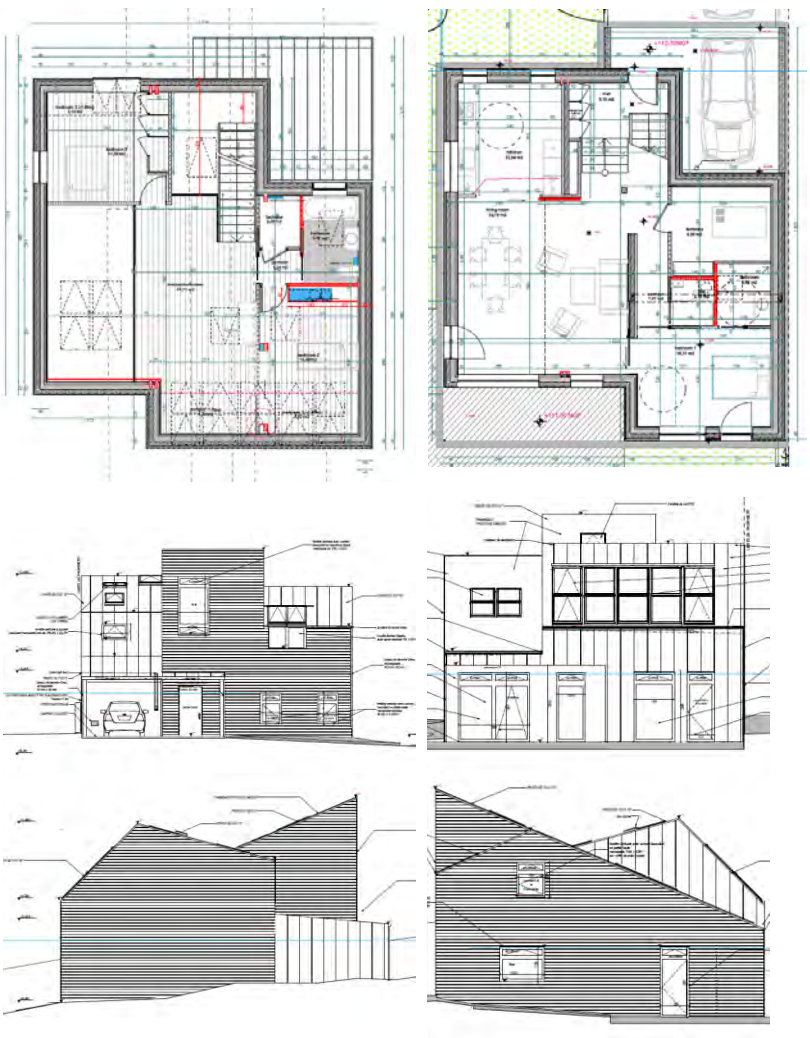

Fig 4. ARCHITECTURAL DRAWINGS AND SECTIONS.

Table.2 BUILDING PROPERTIES

Property	Unit	Value
Occupant density	m^2/p	34
Hours of occupancy	h/week	134
Sensible Internal Load	(W/m^2)	3,45
Window U-value	W/m^2K	1.4
Window g-value	(-)	0.30 (South) and 0.48 (North)
Wall U-value	W/m^2K	0.14
Roof U-value	W/m^2K	0.10
Floor U-value	W/m^2K	0.12
Thermal Mass (ISO 13790)	-	Light
Window to Wall Ratio	%	31.2
Air-tightness (@50 Pa)	1/h	1.85
Shape Coefficient (1/m)	%	0.584

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	●
Energy costs	•
Solar Loads	⬤
Internal Loads	●
External Noise	•
Internal Noise Propagation	•
Air Pollution	⬤
Rain Ingress	•
Insect prevention	•
Burglary prevention	●
Privacy	•
Air Leakage	●

3. Energy Systems

The home’s energy concept is based on optimal use of renewable resources (solar energy, natural light and fresh air) to minimize the need for air conditioning in summer, reduce heating in winter, and reduce artificial lighting use.

3.1 Heating System

The house is heated through a ground heating system, with independent temperature management in each room.
The heating generation is provided by an air-to-water heat pump able to use the installed thermal collectors to increase its efficiency. The house is designed with a dedicated roof pitch of 45° in order to optimize the efficiency of the thermal collectors.

- When there is sufficient sun provision, solar collectors are directly used to heat up a hot water storage tank (1000 L)
- When there is reduced sun provision (not sufficient for using thermal collector directly), thermal collectors are used as the hot source for the heat pump in order to increase its efficiency
- When no available solar radiation, the heat pump runs its default mode as a standard air-to-water heat pump

Both domestic hot water and heating can be extracted directly from the storage tank in order to prioritize renewable sun energy before using the heat pump.

Fig. 5 GROUND HEATING SYSTEM (BEFORE CONCRETE SLAB)

Fig. 6 SOLAR HEAT PUMP (SONNENKRAFT)

3.2 Electrical Power Supply (PV, wind turbine & Microgrid)

Photovoltaic tiles were installed on a dedicated roof pitch of 23° in order to maximize their annual efficiency.
42 m² of photovoltaic tiles have produced 58,8 kWhPE/(m².yr) according to the measurements, which is aligned with predictions (59 kWhPE/(m².yr)).

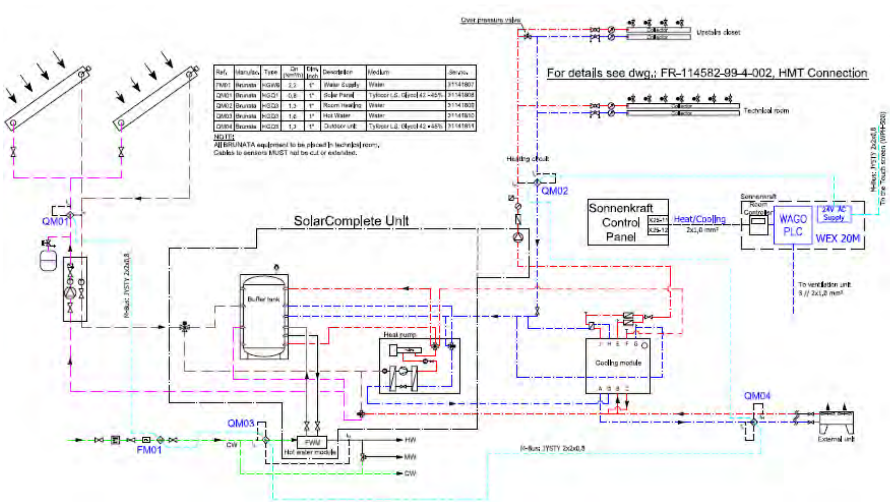

Fig.7 HYDRAULIC SCHEME OF HEATING AND HOT WATER SYSTEM

4. Ventilative Cooling

4.1 Principles

The ventilative cooling system of Maison Air et Lumière was originally designed as a hybrid system, using both natural ventilation and mechanical ventilation with heat recovery in order to maintain the house at a good level of thermal comfort. It is also used to ensure a good indoor air quality during both winter and summer season.
Mechanical ventilation with heat recovery is preferred during the winter season, whereas natural ventilation is preferred during the summer season using the openable windows.
The winter and summer season are dynamically defined on the basis of the daily mean exterior temperature, which has to be higher than 12°C on the previous day to turn on the summer mode (redefined each day).
During this period, automated façade and roof windows can be automatically opened if there are both a risk of overheating and a good potential for ventilative cooling ($T_{ext} < T_{int} + \Delta T$). This double condition can be assessed for each room of the house.

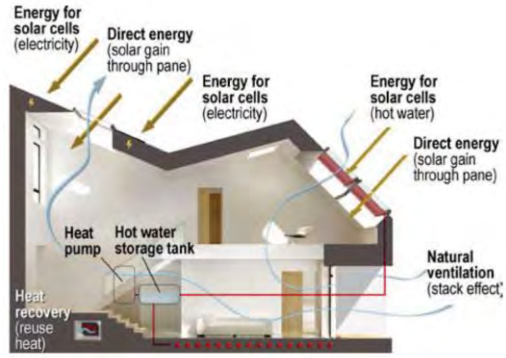

Fig. 8 VENTILATIVE COOLING PRINCIPLE

4.2 Components

Ventilative cooling is provided by the following components:

- Millet's facade windows equipped with WindowMaster's actuators
- VELUX INTEGRA automated roof windows

Both components are using the io-homecontrol protocol to be operated by a centralized intelligent system.
There are 15 different window sizes in the house. The free opening area is calculated as the accumulated area of all the components, here 5.64 m².

In addition, all rooms are equipped, among others, with air temperature sensors, and an exterior weather station providing the shaded exterior temperature.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area (range for windows used)	0,21-0.45 m²
Discharge Coefficient (Cd)	0.7
Overall Dimensions (1 typical window) #VELUX GGL M06	0.78m width x 1.18m height
Porosity (A_w/A_f)	2,1%
Q (@ Vel = / ΔP =	n50 = 1,85 h^{-1}

Fig. 10 BOTTOM-HUNG FAÇADE WINDOWS AND ROOF WINDOWS USED IN MAISON AIR ET LUMIÈRE

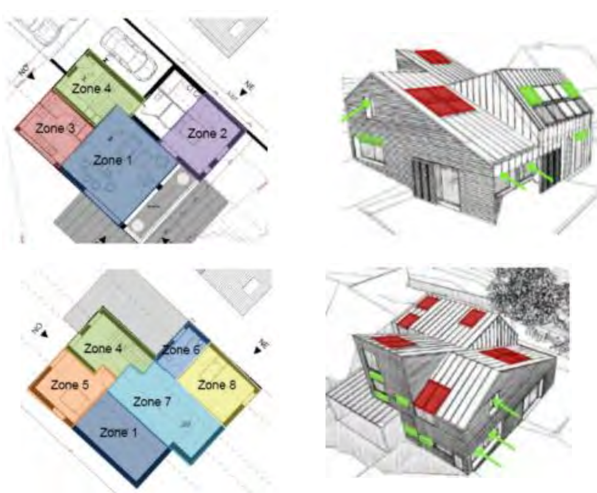

Fig. 9 NATURAL VENTILATION SYSTEM: ZONES, INLET AND OUTLET WINDOWS

5. Control Strategy

5.1 Control Strategy Overview

The control strategy was originally designed to optimize ventilative cooling based on room temperature and outdoor temperature.
This system has demonstrated its efficiency during the unoccupied period (1 year), but it has shown some limits as soon as the family moved into the house: indeed, the opening of windows happened as soon as there was at the same time a need for ventilative cooling and a potential (outdoor temperature lower than indoor temperature). This control strategy was not convenient for the family as the understanding of windows opening was not obvious to the occupants: they were expecting to observe the same opening schedules day after day, which was of course not the case due to the dynamic design (same reactions were observed regarding the control strategy of external awning blinds).
After a few weeks, a decision was taken to switch to hourly-based schedules, in order to increase the family's acceptance. This new strategy was far more efficient as the family was not turning off the system as they were doing before.

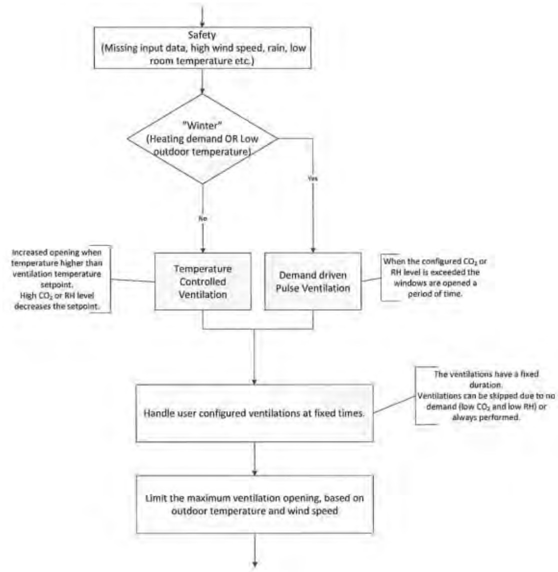

Fig. 11 CONTROL STRATEGY FLOWCHART

5.2 Control Strategy Description

The control strategy of ventilation in summer was based on indoor and outdoor temperatures, aiming at cooling the house through window openings as soon as there is, at the same time a need and a potential for ventilative cooling.
Nevertheless, the use of natural ventilation for cooling purposes was also balanced with the optimization of indoor air quality,, aiming at keeping both CO_2 and RH levels within the recommended ranges.

Parameter	Input/Output/Target	Value
Room temperature	Input	Variable
Room summer comfort temperature	Target	20°C
Outdoor temperature	Input	Variable
Outdoor temperature limit value	Target	12°C
Rain (to close windows)	Input	Yes/No

Table. 5 CONTROL STRATEGY TABLE

6. Design Simulation

6.1 Summary

To calculate natural ventilation accurately, a BSIM model (integrated PC tool for analysing buildings and installations) using both the single zone model (SZM), and the multizone model (MZM). The bedrooms and kitchen are simulated using the SZM. The living room and mezzanine are interconnected, therefore the MZM needs to be used. Due to the use of the MZM, computing time significantly increased compared to a regular BSim model. The windows are controlled after temperature and CO_2. The max air change is limited to approximately 5 air changes pr. hour (h^{-1}).

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	RT2005 (F)	Define building features of materials/systems
Concept Design	VELUX Daylight Visualizer	Initial Daylight Check
Detailed Design	BSim (DK)	Thermal Comfort analysis & ACR
Construction Design	RT2012 (F)	Energy performance

6.2 Simulation of overheating risk

Below the operative temperatures are plotted as a function of the running mean temperature for e.g. the Living room.

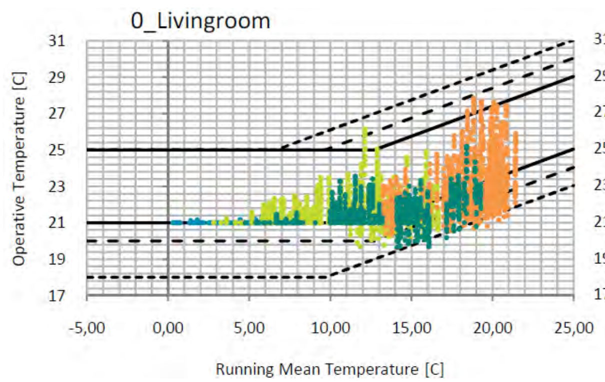

Fig. 15 OVERHEATING EVALUATION BASED ON EN 15251

6.3 Simulation of ACR

The darker column in Figure 14 shows the average air change rate for all non-winter hours, while the lighter column shows the average air change rate of when Op. temp > 25 °C. This column is of particular importance as it indicates if there is sufficient natural ventilation in the zone. BSim will maximize the air change rate to cool the zone because Top > 25°C. The maximum air change rate is 5 h^{-1}.. The average air change rate is lower due to days with low wind velocities. However, the closer the average air change is to 5 h^{-1}, the better the natural ventilation works.

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	21,2°C (avg. during day)
T_z , Summer Operative Temp	-
Overheating criteria	Adaptive Thermal Comfort
Min IAQ air supply rate	~ 0,4 ACH
Cooling air supply rate	No mechanical cooling
Noise Level Rating	-

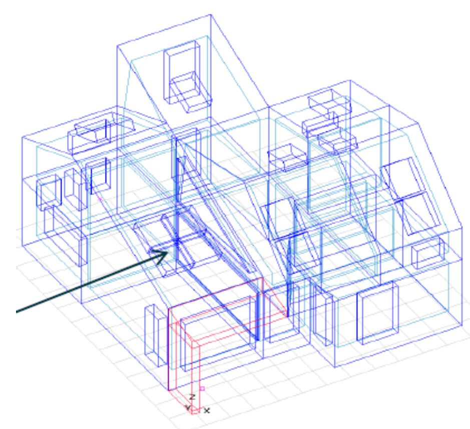

Fig. 13 SIMULATION MODEL SETUP IN BSIM

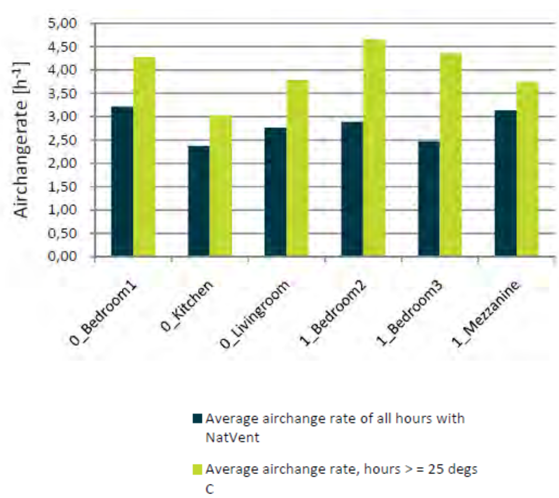

Fig. 14 AIR CHANGE RATES

7. Performance Evaluation

7.1 Ventilative cooling research project: method

A research project on the evaluation of ventilative cooling was conducted by Armines (Ecole des Mines) in France. This project was aiming at assessing the efficiency of ventilative cooling in Maison Air et Lumière, and at using the on-site measurements to validate the simulation models used for carrying out natural ventilation and thermal comfort studies.

This project was carried out in several steps:

1. Measure on a test bench the aeraulic features of roof windows (discharge coefficients…)
2. Establish and operate different "critical" ventilation scenarios (no ventilation, full-time ventilation, optimized ventilation) in order to perform on-site tests with extreme cases
3. Perform on-site measurements on both thermal environment (indoor and outdoor temperatures) and ventilation flows (air speed through windows, pressure differences, overall air change rates through tracer gas)
4. Run dynamic simulations based on the implemented ventilation scenarios and on the measured outdoor conditions (exterior temperature, sun radiation, wind speed and direction)
5. Compare observed and simulated ventilation flows, air change rates and indoor temperatures
6. Evaluate the accuracy of the simulation tool and assess the efficiency of ventilative cooling

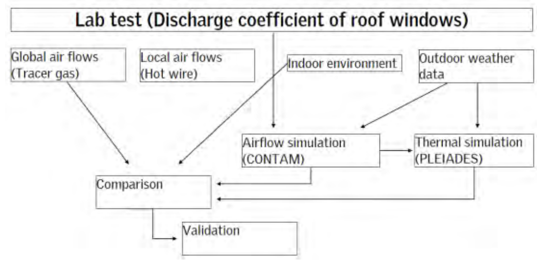

Fig. 16 RESULTS FROM VARIOUS EVALUATIONS

Table 8 PERCENTAGE HOURS EXCEEDANCE (FOR LIVING ROOM)

Parameter	Sept 2012-Sept 2013
Total Hours > 25°C	7%
Occ Hours > 25°C	5%
Total Hours > 28°C	1%
Occ Hours > 28°C	0,8%

7.2 Aeraulic characterization of roof windows

An unmissable part of the project was the evaluation of aeraulic features of roof windows. A dedicated test bench was built in order to evaluate accurate air flows passing through the geometrical free area of the window.

Fig. 17 TEST BENCH FOR ROOF WINDOWS AERAULIC CHARACTERIZATION

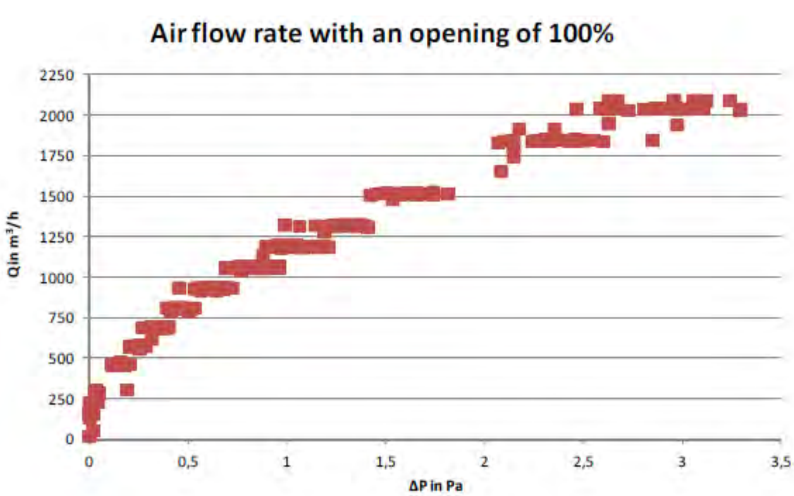

Fig. 18 MEASURED AIR FLOW RATES THROUGH FREE AREA OF ROOF WINDOW

7.3 Air flow measurements (tracer gas method)

The following graph shows the tracer gas (CO_2) decay curve measured for 2 different ventilation scenarios at two different times of a day.
By deriving these curves trough a logarithm function, it is possible to calculate global air change rates of the house for the different scenarios (see Table 10).

7.4 Internal temperatures and simulation accuracy

Figure 19 shows the evolution of measured and simulated internal temperatures on a representative day in August.
On average, the difference between the simulated and measured temperatures are close to 1°C.

7.5 Conclusion and results

The measurements performed in Maison Air et Lumière have shown that during the period without ventilation (end of July 2012), the temperature reached 35°C. Ventilative cooling allowed a rapid reduction of this overheating, and temperatures stayed within the comfort interval (less than 27°C in occupied rooms) during the rest of the measurement period, particularly using controlled ventilation. This shows that during summer, ventilative cooling is efficient, as high air change rates are possible even with low temperature differences and relatively low wind speed (between 2 and 3 m/s).
In complement of measurements, thermal dynamic simulation has been used to evaluate the interest of ventilative cooling by comparing temperature profiles with and without ventilation during the same period, i.e. in the same climatic conditions. According to these results, indoor temperatures were reduced by about 5°C thanks to ventilative cooling.
Simulation has been compared to measurements, which gives some confidence in the reliability of the model regarding both the evaluation of temperatures and air flow rates: even without any model calibration, there is around 1°C difference on the average overheating (average difference between indoor and outdoor temperatures).

Table 10 shows a synthesis of the key results regarding aeraulic and thermal performance of ventilative cooling.

Figure 22 shows the monthly spread of thermal comfort in the room with the strongest inflow of light, i.e. the living room. During the summer months, the room was in category 1 with only a few hours in category 2 and 3. In winter, the room is in category 2 to 4. To obtain category 1 in winter, the indoor temperature must be above 21°C. The occupants themselves chose to have a temperature below 21°C.

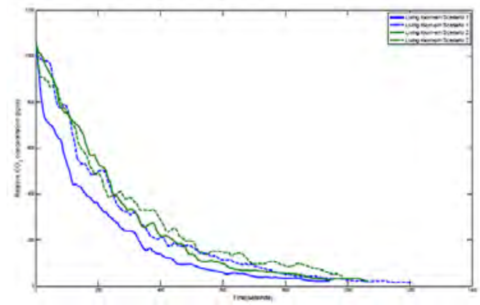

Fig. 20 MEASURED TRACER GAS DECAY CURVES

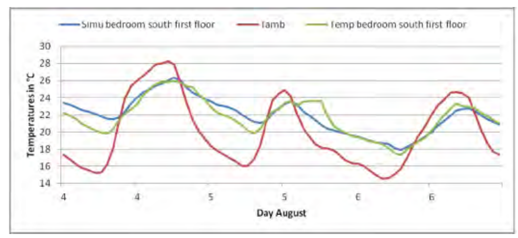

Fig. 19 COMPARISON BETWEEN SIMULATED AND MEASURED INDOOR TEMPERATURES

Table 10 TABULATED RESULTS

	Representative air flows in ACH [h⁻¹]		Representative average temperature difference (Tint – Text)		
	Mornin g	Aftern oon	No ventilati on	Full-time ventilati on	Control ventilati on
Simulatio n value	14 ACH	13,2 ACH	6 °C	1,5 °C	0 °C
Measure ment value	13,4 ACH	10,6 ACH	4,8 °C	0,2 °C	-0,3 °C

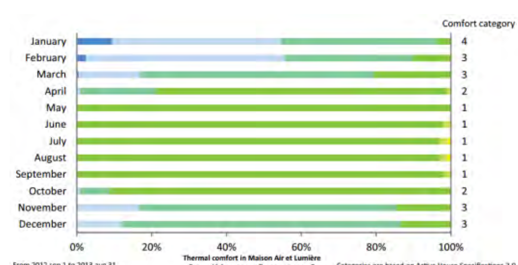

Fig. 22 MONTHLY SPREAD OF THERMAL COMFORT IN LIVING ROOM

8. Lessons Learned

8.1 Summary

Maison Air et Lumière experienced no overheating in summer despite the high daylight levels which could have led to overheating. All rooms achieve Active House category 1 with regards to overheating which is the category with the most strict temperature requirements.
During winter the main rooms achieve Active House category 2 or 3. This corresponds to a temperature between 19°C and 20°C and that is an active choice of the occupants, i.e. the temperature at which they felt comfortable in the house. This could indicate that the Active House requirements for minimum temperature in winter may be a bit too strict.

8.2 Detailed list of lessons learned

Table. 12 Key Lessons Learned **Design and Construction**

Item	Lesson	Importance
1	People want to have the control of the system – not wanting the system to be deciding on its own	High
2	Ventilative cooling is very efficient. Combined with good use of solar shading, it allowed reduced indoor temperatures	High

Table. 13 Key Lessons Learned **Operation / Post Occupancy**

Item	Lesson	Importance
1	Around 5°C indoor temperature reduction has been obtained by the use of ventilative cooling, both by simulation and measurement: with similar outdoor conditions, the interior air temperature of the house was 5°C lower using ventilative cooling than without any opening of windows.	High
2	MAL experienced no overheating in summer despite high daylight levels	High
3	All rooms achieve Active House category 1 with regards to overheating which is the category with the most strict temperature requirements.	High
4	The living room had particularly high daylight levels, and therefore had a high potential for overheating. Practically no episodes of overheating were seen in this room	High
5	(Peuportier et al, 2013) measured the air change rates achieved with natural ventilation as the means of ventilative cooling, which were in the range of 10 to 22 ACH achieved with limited wind velocities (2-3 m/s) and low temperature difference between outside and inside (lower than 3 K)	High

9. References & Key Contacts

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Evaluation of ventilative cooling in a single family house - Characterization and modelling of natural ventilation, N. Dupin, B. Peuportier, M. Cohen, B. Favre, E. Vorger, World Sustainable Buildings Conference (Barcelona, 2014) 2014/10/29

9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
Nomade Architectes, FR	Architect	Raphael Chivot https://www.linkedin.com/in/raphael-chivot-39777a93/
Armines (Ecole des Mines), FR	Research project manager	Bruno Peuportier https://www.linkedin.com/in/bruno-peuportier-21489439/
Cardonnel Ingénierie, FR	Design engineer	Christian Cardonnel https://www.linkedin.com/in/christian-cardonnel-83604393/
Esbensen, DK	Consulting engineer	Rob Bindels https://www.linkedin.com/in/rob-bindels-0a823711/
VELUX France, FR	Project manager	Catherine Juillard Catherine.Juillard@velux.com +33 1 64 54 24 61 https://www.linkedin.com/in/catherine-juillard-19842952/
VELUX France, FR	Thermal engineer	Nicolas Dupin nicolas.dupin@velux.com +45 45 16 78 70 www.linkedin.com/in/nicolas-dupin-21653575

10_IT_Mascalucia ZEB

Key Features & Climate

IEA EBC Annex 62 The IEA project on ventilative cooling

1.1 Introduction

Zero energy certified passive house in Mascalucia - Sicily

The Botticelli project is a first example of a fully-monitored Zero-Energy Building located in a warm Mediterrenean climate. The building, located in the municipality of Mascalucia (Catania) in the region of Sicily, is certified according to the Passivhaus standard, which sets high-quality requirements in terms of thermal performance and air tightness. The building is conceived in order to minimize the energy need for heating and cooling; in particular, it exploits natural ventilation strategies such as cross-ventilation and night ventilative cooling (Section 4). The external patio and the layout of the window openings have been studied to enhance natural ventilation. The remaining energy need is covered by (i) the local production of renewable energy by means of photovoltaic modules, (ii) a thermal solar system coupled to a heat pump and (iii) an Earth-to-Air Heat Exchanger (EAHE) coupled to the mechanical ventilation system. In particular, the EAHE provides pre-heating or pre-cooling to the fresh air entering the ventilation system, while a heat recovery unit further reduces the heating/cooling load required to the coils of the HVAC system. The building is automatically controlled by a building automation system supported by KNX protocol. The building is continuously inhabited by a family, which is closely collaborating with the research team to the aim of studying the impact of various control strategies on the thermal comfort and indoor air quality levels.

Fig.1 Zero energy certified passive house in Mediterranean climate, Sicily - Italy

Table.1 Key Information about building

Location	Sicily, Italy
Building Type	Residential
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Hybrid
Year of Completion	2013
Floor Area (m^2)	144
Shape Coefficient (m^2/m^3)	1,57
Openable Area to Floor Area Ratio (%)	14,7
Window to Wall Ratio (%)	25
Sensible Internal Load (W/m^2)	2
Climate Zone (KG)	Csa
No. of Days with T_e max > 25	106
Cooling Season Humidity	Low
Heating Degree days (Kd)	1271

1.2 Local Climate

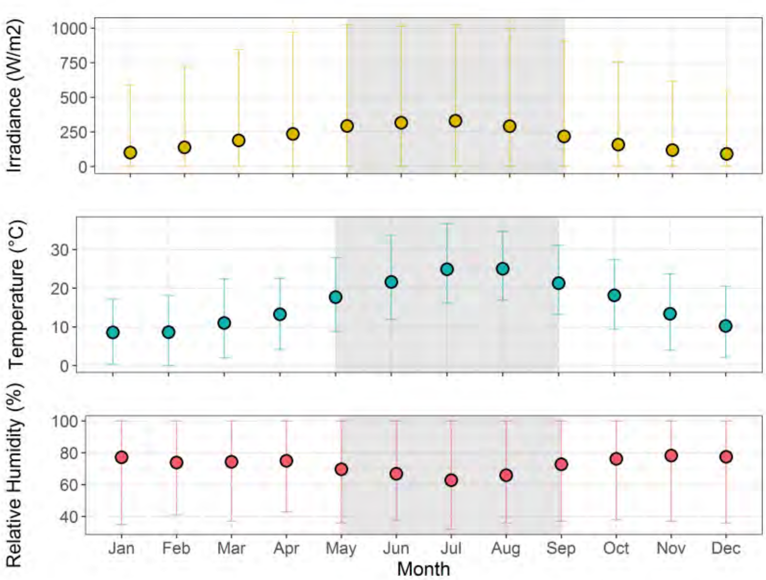

Fig.2 Mean, maximum and minimum external conditions in Mascalucia using TMY3 from Meteonorm 7 (cooling season shown shaded)

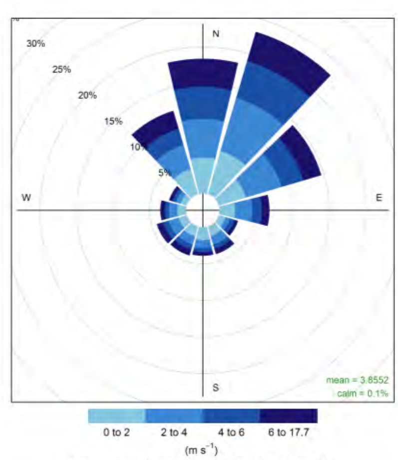

Fig.3 Wind rose for Mascalucia

2. Building Information

2.1 Description

Botticelli is a first example of a Net Zero Energy Building (NZEB) located in a warm Mediterrenean climate. The building, certified according to Passivhaus standard, is a single-family house continuously monitored for research purposes and controlled by a building automation system, which is in charge of harmonizing the operation of the mechanical ventilation system, the renewable sources (PV panels and a tehrmal solar panel) and an Earth-to-Air Heat Exchanger (EAHE).
The building has a single floor and is composed by a kitchen-living room, three bedrooms, a study room and three bathrooms/toilets (Figure 4).
The layout has a U shape, with an internal patio communicating with the garden; this layout has been chosen to better exploit natural ventilation strategies (higher Openable Area to Floor Area Ratio compared to compact buildings).

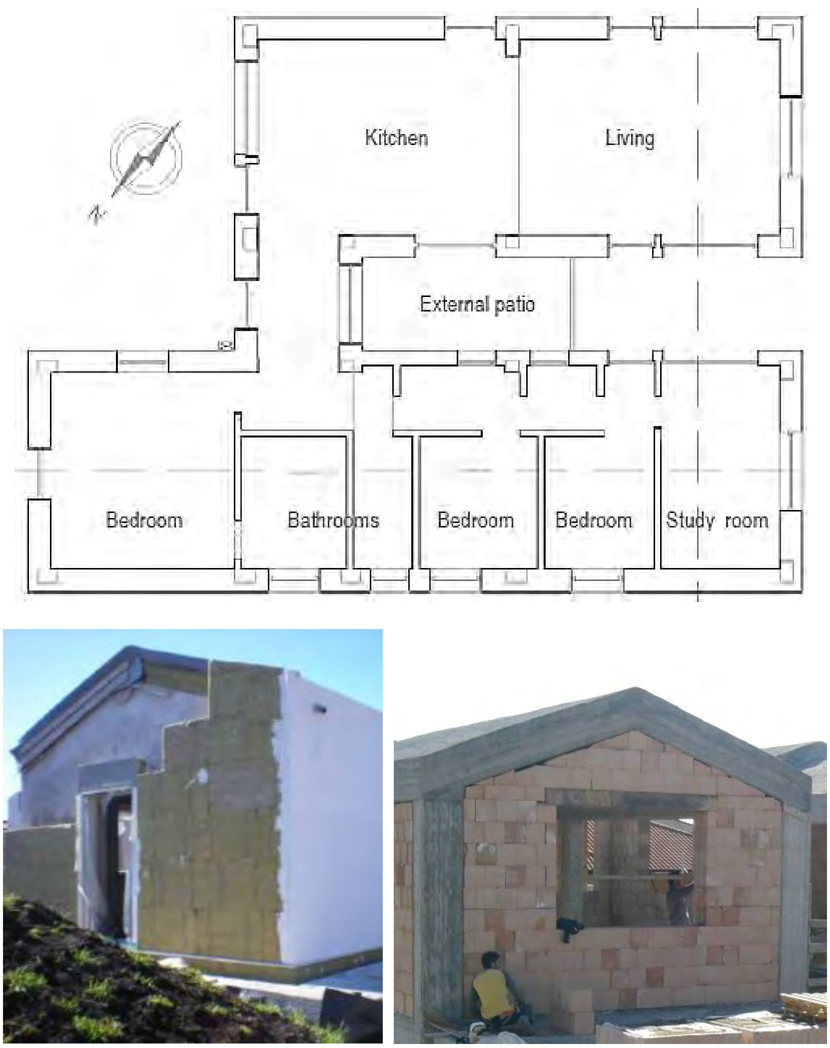

Fig 4. Architectural drawings and construction site photos

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	48
Hours of occupancy	h/week	145
Sensible Internal Load	(W/m^2)	2
Window U-value	W/m^2K	0,90-1,10
Window g-value	(-)	0,1
Wall U-value	W/m^2K	0,13
Roof U-value	W/m^2K	0,13
Floor U-value	W/m^2K	0,23
Q-value (from Japan)	$(W/m^2)/K$	1,15
Thermal Mass (ISO 13790)	-	Very Heavy
Window to Wall Ratio	%	25
Air-tightness (@50 Pa)	1/h	> 0,6
Shape Coefficient (m^2/m^3)	-	1,57

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	●
Energy costs	⬤
Solar Loads	⬤
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	•
Insect prevention	•
Burglary prevention	●
Privacy	•
Air Leakage	●

3. Energy Systems

The Botticelli project has been designed to be operated using hybrid ventilation strategies. In particular, the mechanical ventilation system is briefly presented below.

3.1 Heating System

Figure 7 shows a scheme of the building plants. The fresh air passes through an Earth-to-Air Heat Exchanger, then it goes through a heat recovery unit and is finally processed by heating/cooling coils before being distributed to the bedrooms and the kitchen-living room. The exhaust air is extracted from the bathrooms and the kitchen in order to remove the internal pollutants.
As concerns the hydronic circuit, a solar thermal panel feeds a hot water tank for the domestic hot water and the heating coil in winter time.
In summer time the cooling water is chilled by a heat pump and by a rainwater tank that is used also for watering the garden.
The green circles in Figure 7 represent the measurement points for air temperature, relative humidity, CO2 and VOCs, and for water temperature and mass-flow.

3.2 PV panels and solar thermal panels

The roof of the building is equipped with a PV system, with peak power 8.14 kW. The electricity production by the PV panels is continuously monitored and compared with the instantaneous (1 min) energy need of the building. Over the whole year and for most of the months, the building results “energy positive”, meaning that the local energy production exceeds the energy need.

Fig. 5 MECHANICAL VENTILATION SYSTEM COMPONENTS AND INSTALLED SENSORS

Fig. 6 PV PANELS AND SOLAR THERMAL PANELS

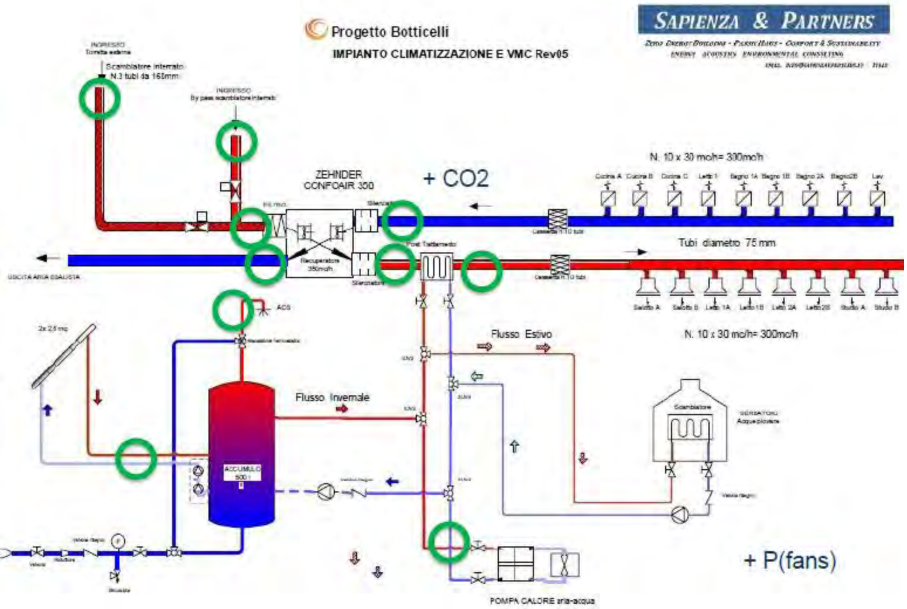

Fig. 7 SCHEME OF THE HVAC SYSTEM WITH MONITORING POINTS (GREEN CIRCLES)

Fig. 8 EAHE AND MONITORING SENSORS INSTALLATION IN THE CONSTRUCTION SITE

4. Ventilative Cooling

4.1 Principles

The building has been designed to exploit cross-ventilation in the kitchen-living room, in the study room and in two bedrooms (Figures 4 and 20).
In addition, the large openings in the living room promote high airflow rates, the entrance of daylight and a view on the garden.
During mid seasons and in summer time, the building allows the occupants to adopt night ventilative cooling (provided that the external air temperature is e.g. 2°C lower than the internal air temperature, as discussed in Section 5).

Fig. 9 OPENABLE WINDOWS WITH AUTOMATIC EXTERNAL BLINDS AND THE EXTERNAL PATIO

4.2 Windows

The windows installed are of the type air-filled triple-glazing with PVC frames (Figures 9) with external automatic shadings.
The building is divided into two parts separated by a central patio (Figure 9), which is in communication with the garden. The concept of the patio, which follows the architectural tradition of Sicilian houses, offers advantages in terms of comfort and energy efficiency: the layout becomes more articulated, allowing for a better exploitation of cross-flow ventilation and night-ventilation strategies.
Table 4 reports the main features of the window components.

Table. 4 FEATURES OF WINDOW COMPONENTS

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area	0,17 - 2,05 m^2
Discharge Coefficient (Cd)	TBC
Overall Dimensions	various
Porosity (A_w/A_f)	14,7 %
Q (@ Vel = x / ΔP = x)	TBC

4.3 Earth-to-Air Heat Exchanger (EAHE)

The Earth-to-Air Heat Exchanger provides pre-heating or pre-cooling of the external air entering the ventilation system. It has been carefully designed considering the geometric limits of the lot and the soil type. The L-shape of the pipes derives from a tradeoff between different requirements: (i) reducing the thermal influence of the building and of the lot boundary walls on the operation of the EAHE, (ii) connecting the pipes to the conveyor box of the ventilation system and (iii) facilitating the periodic cleaning of the pipes. The design parameters of an EAHE are the type of the backfill soil material, the characteristics of the pipes (depth of the bed, length, spacing, number and section diameter) and the nominal airflow of the fan (for more information, see Carlucci et al., 2014). The EAHE can be excluded thanks to a by-pass duct whenever the air temperature at the outlet of the EAHE is higher than the outdoor air temperature.

Fig. 10 INLET DUCTS OF THE EAHE

5. Control Strategy

The control system relies on a BACnet structure, which communicates with BACnet, Konnex and Meter-bus modules through gateways. The use of three communication protocols derives from the various (and only partially overlapping) potentialities/functions provided by each protocol.

The control system regulates the following functions:

- Mechanical ventilation for heating and cooling
- Production of Domestic How Water and hot water for radiators
- Control of solar shading (depending on solar irradiance, internal temperature or pre-defined schedules) and artificial lighting
- Storing of rain water and watering of the garden
- Visualisation, interfaces and communication with occupants

In particular, the control strategy for the operation of the ventilation system is schematized in Figure 11. The fans' speed is adjusted according to the measured level of carbon dioxide (CO2), Volatile Organic Compounds (VOC) and Relative Humidity (RH), as exemplified in Table 5. The mechanical ventilation shuts when one of the windows or the entrance door is left open for a certain time (1 min or higher, depending on the setting).

Table. 5 CONTROL STRATEGY PARAMETERS

Parameter	Input/Output/ Target	Value
Internal Air Temperature	Input	Variable
Relative humidity	Input	Variable
CO_2	Input	Variable
Volatile Organic Compounds	Input	Variable
External Temperature	Input	Variable
Ventilation Door Position	Output	0 / 100 %
Fan speed	Output	Variable

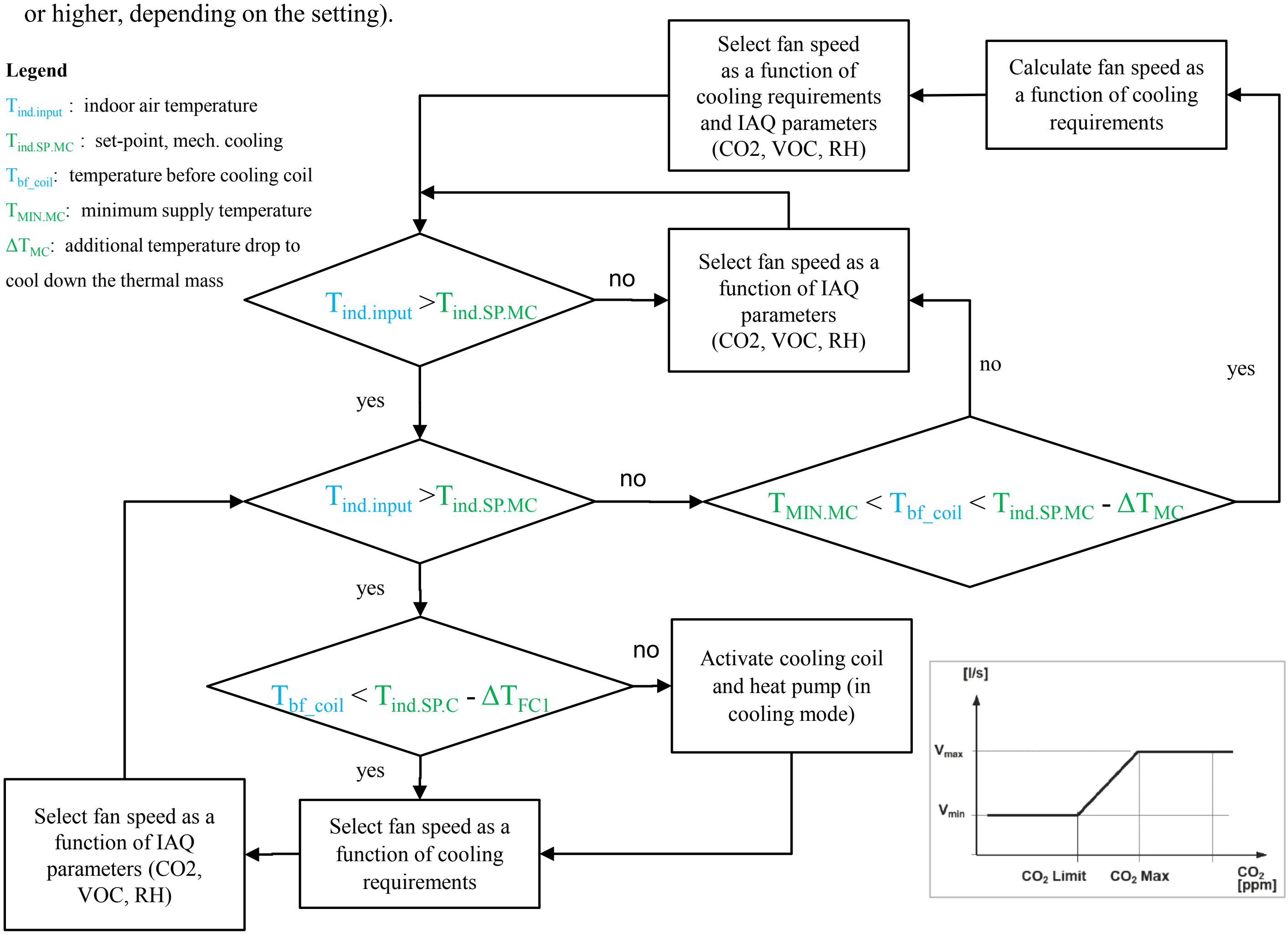

Fig. 11 CONTROL STRATEGY. BOTTOM RIGHT: VARIATION OF THE VOLUMETRIC FLOW RATE AS A FUNCTION OF CO2 CONCENTRATION LEVEL

6. Design Simulation

6.1 Summary

The thermal behaviour of the building has been simulated using the building energy simulation tool EnergyPlus v. 6.0.0.23. The ventilation rates and the air infiltration are calculated using the AirflowNetwork module in order to better calculate the contribution of natural ventilation and infiltration.

During the concept design phase, a large number of passive strategies and buildings variants were simulated and analyzed. In particular, the simulationists adopted a particle swarm optimization algorithm via the optimization engine GenOpt, which guided the selection of (i) the best features of the building envelope elements such as roof, external walls, floor, glazing units at the various orientations and (ii) the best strategies for controlling solar shading devices and the night opening of windows to foster natural ventilation.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Concept Design	PHPP	Define geometrical layout, shape, mean features of building and systems
Detailed Design	EnergyPlus + GenOpt	Define features and solutions for building envelop, ventilation and solar shading control strategies, overheating check and indoor comfort optimization, zero energy balance calculation
Construction Design	PHPP	Final check of energy performance and certification

When a mechanical heating and cooling system (a reversible heat pump) is included in the numerical model of the building (besides the EAHE), requirements about thermal comfort in indoor spaces have been set referring to the Fanger comfort model (PMV-PPD) as implemented in the International standard ISO 7730.

The results showed a good potential of the proposed passive concept (highly insulated building coupled to an EAHE and exploitation of the internal thermal mass) in the selected climate, since the building is expected to have a positive yearly energy balance (local energy production exceeding energy consumption), and to guarantee high levels of comfort according to the Fanger model.

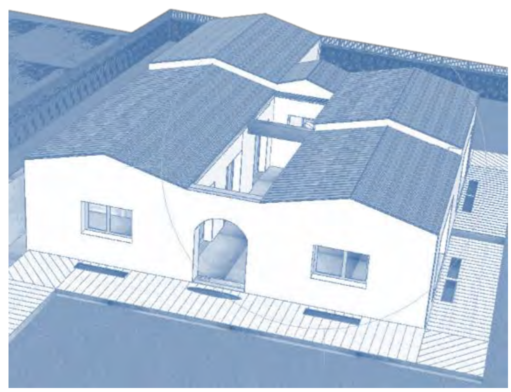

Fig. 12 RENDER OF THE GEOMETRIC MODEL

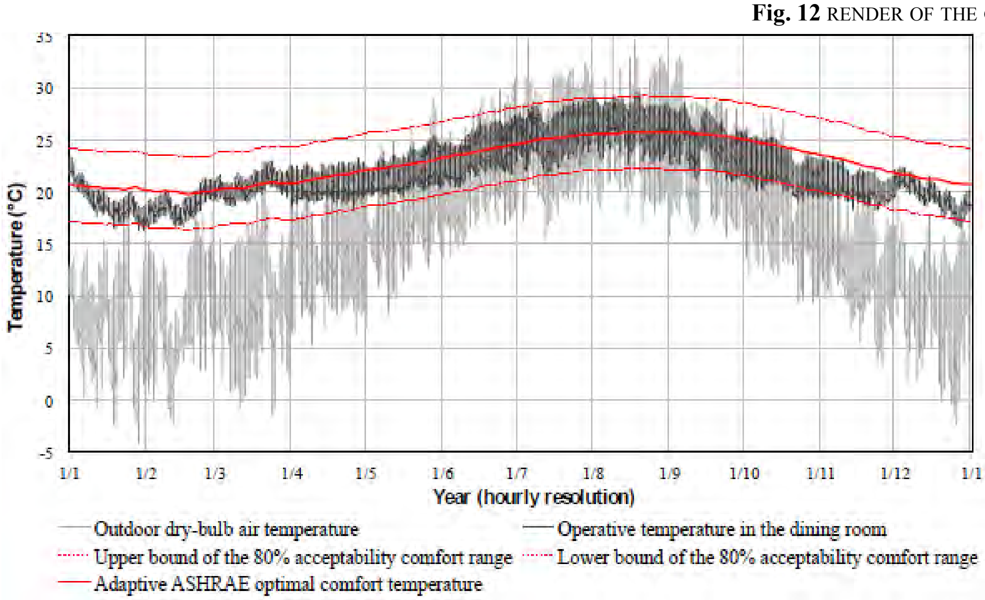

Fig. 13 OPERATIVE TEMPERATURES INSIDE THE LIVING ROOM IN FREE-FLOATING MODE COMPARED WITH THE 80% ACCEPTABILITY RANGE OF THE ASHRAE ADAPTIVE MODEL.

7. Performance Evaluation

7.1 Monitoring set-up

The measurement set-up, consisting of over 130 sensors, has been designed to monitor:

- The thermal and hygrothermal internal conditions
- The indoor air quality
- The external weather conditions
- The energy performance of the mechanical ventilation, the heating and cooling system
- The performance of the Earth-to-Air Heat Exchanger
- The production of electricity by the PV panels and the electricity consumption, with details on the main appliances
- The production of thermal energy by the solar thermal panels and the use of Domestic Hot Water
- The states of the windows, including the solar shading and the mosquito nets
- The states of various actuators/components, such as the dampers of the ventilation systems or the fan motors

Fig. 14 EXTERNAL PATIO AND SENSORS INSTALLED TO MEASURE AIR TEMPERATURE AND RELATIVE HUMIDITY

7.2 Internal temperatures

At present, the building is undergoing a long-term monitoring campaign. Figure 15 shows the evolution of the internal and external air temperatures during the period 4th-21st September 2015, when the building was operated in free-floating mode. The data monitored within the warm season in 2016 are currently being analysed and will be published soon.

We can notice that, while the external air temperature reaches peaks up to 36°C, the internal air temperature shows much smoothes fluctations, with the highest values around 28°C. Since the mechanical ventilation was kept off during the whole period, the comfort levels were guaranteed exclusively by means of passive/low-energy strategies, that is: the operation of the solar shading systems and the activation of the thermal mass of the building. In particular, the solar shading systems were operated manually, usually following the indications provided by the research team and by the interface of the building automation system.

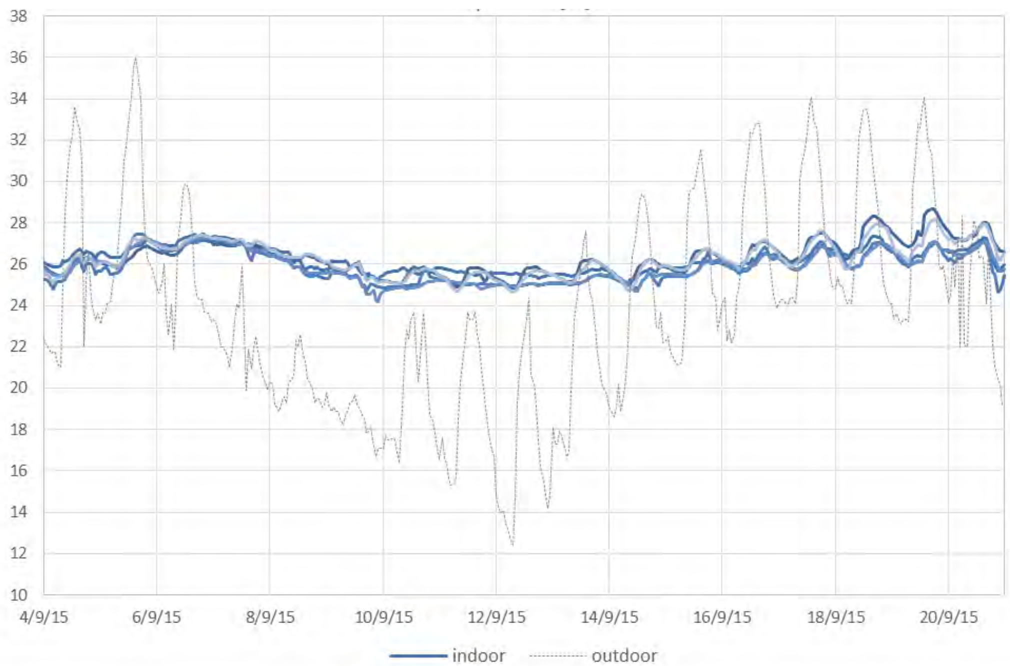

Fig. 15 INDOOR AND EXTERNAL AIR TEMPERATURE – 4TH -21ST SEPTEMBER 2015

7.3 Occupant behaviour concerning window opening

When cooling is needed, the occupants generally opened the windows in the evening and in the first hours of the morning, when the external temperature was lower. However, they sometimes left some windows open also during the central hours of the day, due to the time and effort required by closing all the windows of the house (as emerged from interviews to the occupants). Therefore, the "informed" manual control strategy shows some margins for improvements. The next step will consist in linking the window actuators to the building management system, which will relieve the occupants of the responsibility to correctly set the state of each window. The optimization of the control strategy will also result in additional suggestions to the occupants by the BMS.

Fig. 16 EXAMPLE OF SENSORS INSTALLED IN THE MECHANICAL VENTILATION SYSTEM

7.3 Relative humidity

The temporal evolutions of the internal and external relative humidity (RH) are represented in Figure 18. While the external RH reaches peaks up to 90%, the internal RH remains within the range 35%-70%.

Fig. 17 EXAMPLE OF INDOOR SENSOR INSTALLED TO MEASURE TEMPERATURE, RH, CO2 CONCENTRATION

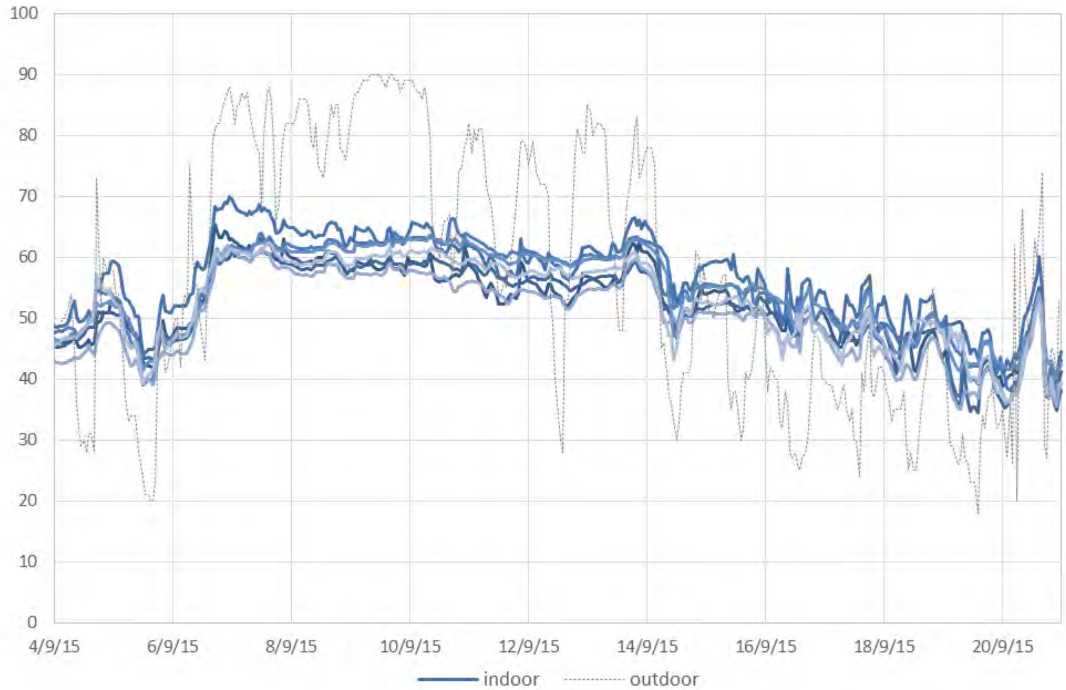

Fig. 18 TEMPORAL EVOLUTION OF RELATIVE HUMIDITY– 4TH -21ST SEPTEMBER 2015

7.4 Indoor Air Quality

Figure 19 shows the evolution of the CO_2 concentration within the analysed period (4th- 21st September 2015). While for most of the time CO_2 concentration levels keep below 1000 ppm, peaks up to 1100-1200 ppm are observed. Given that these peaks occur only occasionaly and that they last for only few hours, they do not indicate serious IAQ issues. However, the observation of CO_2 levels and the identification of the corresponding weather conditions will offer insight and guide towards improvements of the ventilation strategies.

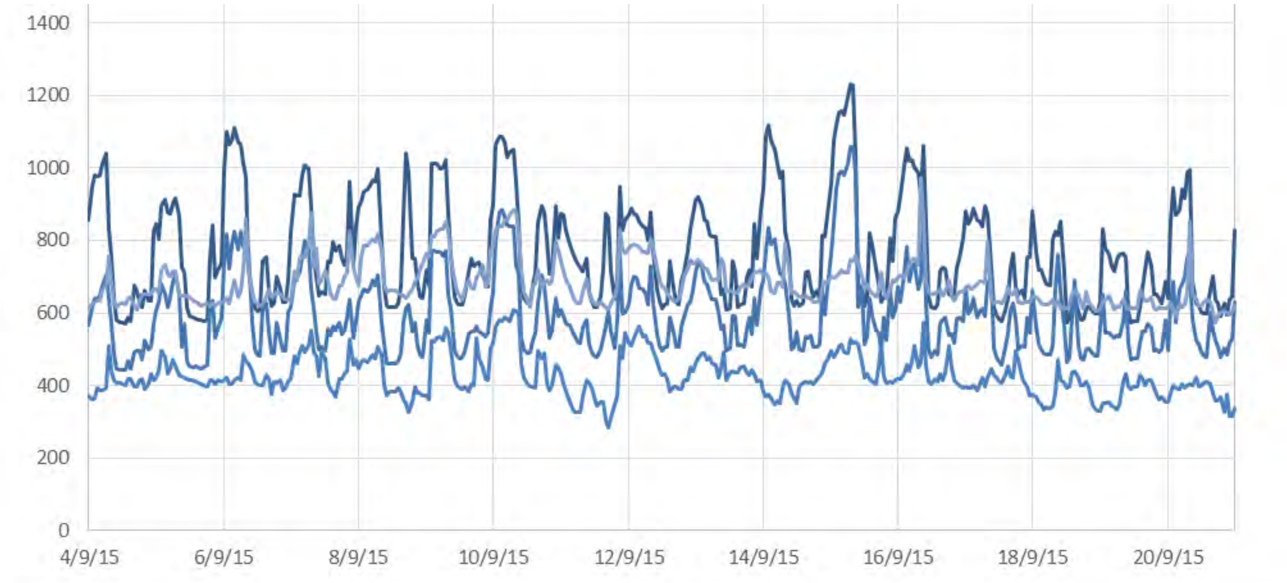

Fig. 19 TEMPORAL EVOLUTION OF CO2 CONCENTRATION – 4TH -21ST SEPTEMBER 2015

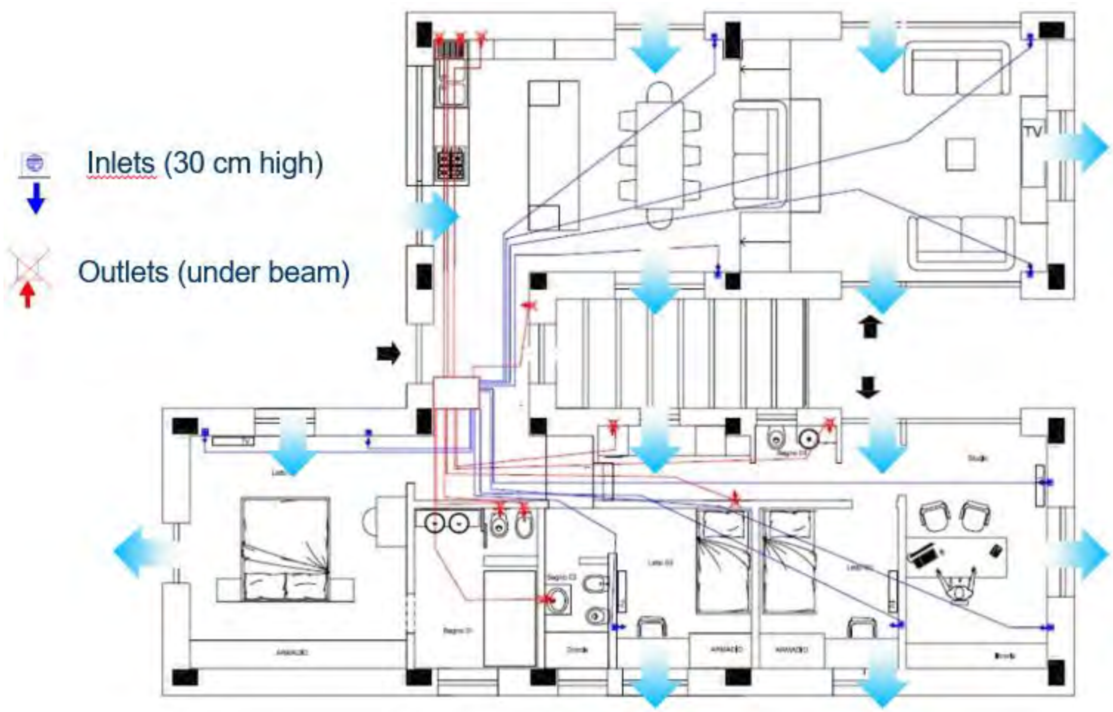

Fig. 20 NATURAL AND MECHANICAL AIR DISTRIBUTION SCHEME

8. Lessons Learned

8.1 Summary

The Botticelli project is the first example of a fully-monitored Net Zero Energy Building in a warm Mediterrenean climate. This single-family house, certified according to Passivhaus standard, combines traditional wisdom of building construction (such as the internal patio) with an advanced control and monitoring system, based on the protocols BACnet, Konnex and Meter-bus. The project aims at studying and optimizing the control strategies in order to minimize the heating and cooling energy need and improve the interaction with the grid, at the same time guaranteeing high levels of thermal comfort and indoor air quality.
Table 7 and Table 8 report the key lessons learned during the phase of design and construction and from operation and post-occupancy surveys.

Fig.21 EXAMPLE OF INDOOR SENSORS INSTALLED TO MEASURE OPERATIVE AND AIR TEMPERATURE, RH, CO2 CONCENTRATION

8.2 Detailed list of lessons learned

Table. 7 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	The harmonisation of three communication protocols (BACnet, Konnex and Meter-bus) has revealed rather complex, requiring both expertize and a trial-and-error approach. However, the complexity of the system also allows (i) the occupants to experiment a broader range of control logics and (ii) the research team to conduct a more detailed monitoring campaign	high

Table. 8 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	Occupants were in general satisfied with the building management system, and in particular with the indications provided by the BMS concerning the opening of the windows. However, opening and closing the windows according to the external air temperature can become burdensome, even when the BMS suggests the best settings. Automatic operation of the window seems the most promising strategy in order to optimise the potential of natural ventilation.	high
2	At present, the solar shading system is provided with mechanical actuators, but the occupant needs to press the buttons in order to operate the actuators. While a display indicates the optimal setting, occupants may decide to ignore the BMS. The optimization (now in phase of completion) of the automatic operation of the shading system will allow for a reduction of the entering solar load and a consequent reduction of the overheating risk	high
3	The exploitation of the thermal mass, a careful operation of the solar shading system and the correct opening of the windows have succeeded in maintaining the internal air temperatures within 28°C most of the time, even when the outside air temperature exceeded 32°C and without using active cooling.	high

9. References & Key Contacts

9.1 References

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A. Janssens, S. Roels, L. Vandaele. Full scale test facilities for evaluation of energy and hygrothermal performances, international DYNASTEE-INIVE workshop, Brussels, 2011.

Web page of end-use Efficiency Research Group – Politecnico di Milano: http://www.eerg.it/index.php?p=Progetti_-_Botticelli

9.1 Key Contacts

Table. 9 KEY PROJECT CONTACTS

Company	Role	Contact
eERG-PoliMI end-use Efficiency Research Group www.eerg.it	Energy simulation, Optimization techniques, Support to Passive house design Energy and comfort monitoring	Eng. Marco Pietrobon marco.pietrobon@polimi.it Prof. Lorenzo Pagliano lorenzo.pagliano@polimi.it Eng. Giulio Cattarin giulio.cattarin@polimi.it
Sapienza & Partners	Building and system design Passive house design	Eng. Carmelo Sapienza
Rockwool	Thermal insulation materials	www.rockwool.it
Siemens	Control and monitoring system	www.siemens.com
PM Plastic Materials	Electrical conduit and pipe	www.pmplasticmaterials.com
Herholdt Controls	Electricity meters	www.hhcontrols.com

1.1 Introduction-NEXUS HAYAMA

NEXUS HAYAMA is training and accommodation for employees of a Japanese pharmaceutical company. The brief rerquired the maximal utilization of the well endowed site to provide functional spaces for long stay training programs and a wide variety of conferences and meetings. This building is located at Syonan International Village in Kanagawa, where many training facilities are concentrated. Key information about builfing is shown Table 1. The building has 5 floors, and the total floor space is 12,835 square meters. It has 190 accommodation rooms, several seminar rooms, a boardroom, a cafeteria and a communal bathroom. The completion date was January 17, 2011.

A variety of environmental technologies are employed such as the skylight louvers which doubles as a solar heat collecting system and natural ventilation system to reach a target of 30% reduction of CO2 for the whole facility and has achieved a self-measured level equivalent to CASBEE-S class (2008 edition) certification.

Fig.1 NEXUS HAYAMA, Kanagawa, Japan

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Kanagawa, Japan
Building Type	Training and Accommodation
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Natural
Year of Completion	2011
Floor Area (m^2)	12835.78
Shape Coefficient (%)	28.7
Openable Area to Floor Area Ratio (%)	3.1
Window to Wall Ratio (%)	55
Sensible Internal Load (W/m^2)	20
Climate Zone (KG)	Cfa
No. of Days with T_e max > 25	93
Cooling Season Humidity	High
Heating Degree days (Kd)	1375

1.2 Local Climate

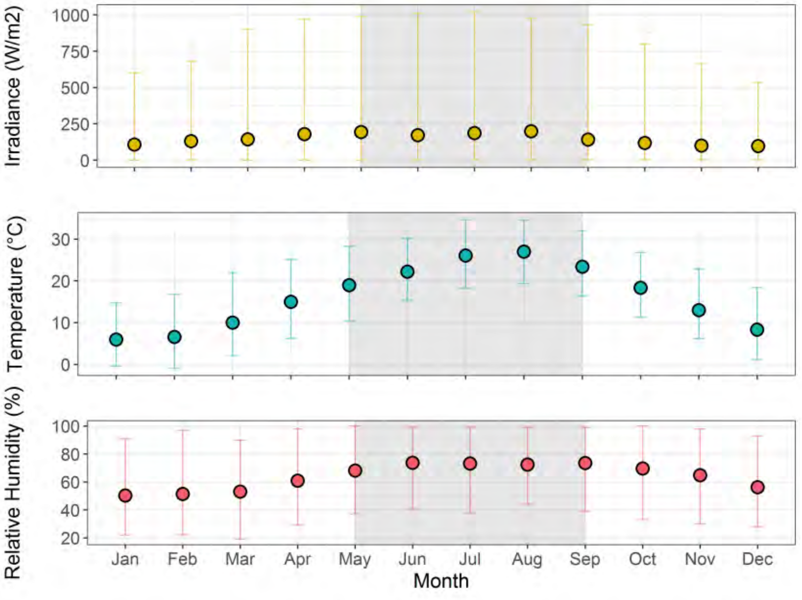


Fig.2 LOCAL MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS FOR KANAGAWA USING A TMY3 (AREA IN GREY IS COOLING SEASON)

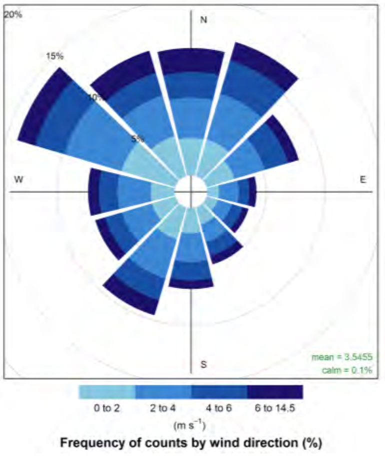


Fig.3 WIND ROSE FOR KANAGAWA

2. Building Information

2.1 Description

The building was sited to spread the Guest Room wings east-west to conform to the contours of the site with the Seminar wing placed in between. The form was kept low so as not to disturb views of neighboring houses and avoid intimidation while maintaining great views of Mount Fuji or Yokosuka Bay from all Guest Rooms.

The Atrium Lounge placed at the center of the facility is a stepped lounging area over three levels in front of the seminar rooms, providing a common space that promotes informal communications between participants. The Lounge is an innovative multi-level semi-exterior space for informal communications, mixing people and refreshing stimulus from its natural environment such as the diffuse sunlight from skylights similar to the dancing light under trees, expansive views out to the Miura Alps to the north, the spatially continuous outdoor Patios and roof gardens.

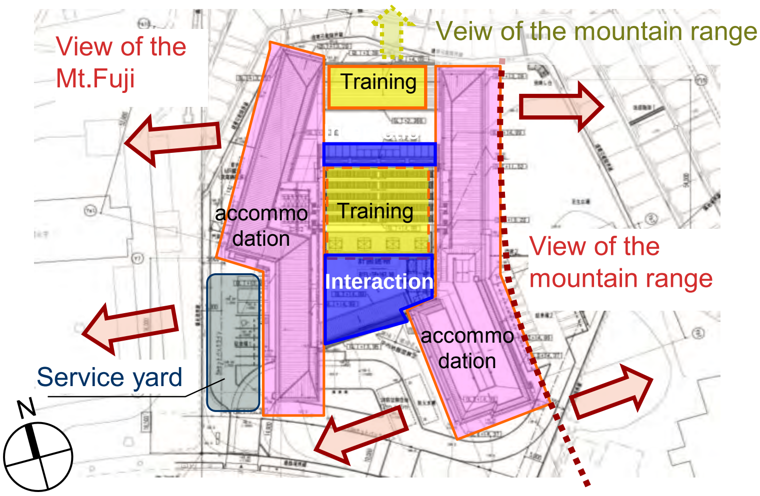


Fig 4. SITE PLAN

Fig 5. CROSS SECTION

Table.2 BUILDING PROPERTIES

Property	Unit	Value
Occupant density	m²/p	10
Hours of occupancy	h/week	168
Sensible Internal Load	(W/m²)	20
Window U-value	W/m²K	1.6
Window g-value	(-)	0.517
Wall U-value	W/m²K	0.86
Roof U-value	W/m²K	0.60
Floor U-value	W/m²K	1.18
Thermal Mass (ISO 13790)	-	Very Heavy
Window to Wall Ratio	%	55
Air-tightness (@50 Pa)	1/h	1.7
Shape Coefficient	1/m	0.287

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	●
Energy costs	⬤
Solar Loads	⬤
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	⬤
Burglary prevention	⬤
Privacy	●
Air Leakage	●

3. Energy Systems

3.1 Multi-use Solar Heating System

Multi-use solar heating and cooling system installed in the NEXUS HAYAMA building represent a key technology. Since the accommodation facility supports long-term stays, contains 190 rooms, and includes a large bathroom facility, it requires significant amounts of hot water. To meet this demand, the design team decided that the use of a solar heating system would be most appropriate. This solar heating system directly converts solar energy into hot water, rendering the system simple and highly efficient. Therefore, the first priority is the production of hot water and the second is space heating and cooling in the summer or on low-occupancy days. The chilled water is used to supply the air handling units (AHUs) and radiant panels. Since the atrium lounge of this building is a large open space, it requires an efficient air conditioning system to minimize energy consumption. Figure 8 shows a schematic of the system, which consists of an evacuated tube collector, a hot water storage tank, a zeolite adsorption chiller, a cooling tower, a pump, and a heat exchanger. The zeolite adsorption chiller used for space cooling can produce chilled water from starting temperatures as low as 60 °C. The evacuated tube collector has an area of 300 m^2 and is located on the roof of the building, facing south, where it is set at a 30° inclination angle. Figure 7 shows an exterior view of the solar heat collector and Figure 9 shows a view looking up from the building's atrium. The collector is positioned outside the skylight window and helps to diffuse the sunlight penetrating into the atrium (Figure 10).

Fig. 6 ATRIUM LOUNGE

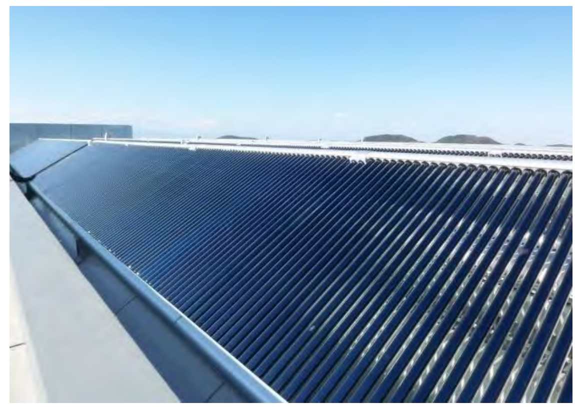


Fig. 7 EVACUATED TUBE COLLECTOR

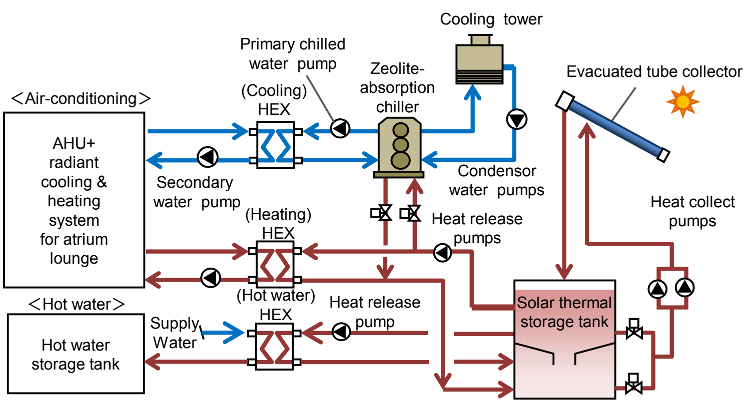


Fig. 8 MULTI-USE SOLAR HEATING AND COOLING SYSTEMS

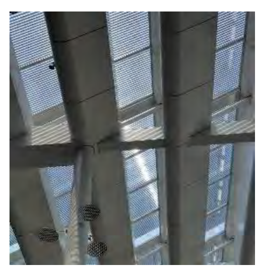


Fig. 9 SOLAR COLLECTOR AS VIEWED FROM THE ATRIUM BELOW

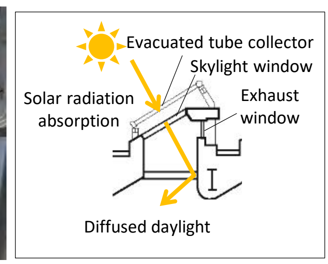


Fig. 10 SECTION OF SKYLIGHT WINDOW

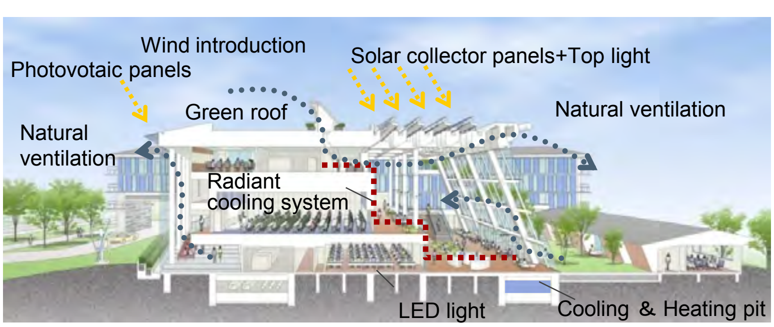


Fig. 11 DIAGRAM OF ENVIRONMENTALLY CONSCIOUS BUILDING

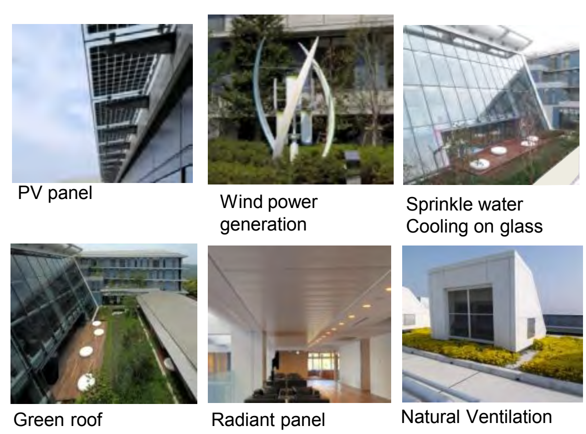


Fig. 12 GREEN TECHNOLOGY IN THIS FACILITY

4. Ventilative Cooling

4.1 Principles

In this building, we are using a natural ventilation system that combines temperature-difference ventilation using a large space and wind-driven ventilation, taking advantage of the strong south wind. The outside air is introduced from the first floor and the top floor to the occupied zone and the exhaust windows in the upper non-occupied zone efficiently cool the living area. (Figure 13)

The thermal environment on the top floor often deteriorates due to the skip floor placed on the step adjacent to the large space. In order to prevent this, a wind extraction window is installed and the outside air is captured on the top floor by using the wind pressure due to the relatively strong wind originating from the ocean. Figure 14 shows the ventilation openings installed on the first floor for introducing the outside air. The outside air is introduced from the cooling & heating pit at the kiosk counter and enters through punched metal parts arranged in the stairs, designed to introduce the outside air directly into the occupied zone of the room. As shown in Figure 15, the wind capture openings, such as the wind tower, were placed on the site after considering the most suitable position with regard to the positive pressure of the external wind. In the intermediate season, a natural ventilation opening via a folding door to the courtyard creates a comfortable semi-outdoor space (Figure 16), while in the summer and winter, an efficient below-floor heating and air conditioning system operates, creating a comfortable space throughout the year.

4.2 Components

The principle of the exhaust opening installed in the non-occupied zone is shown in Figure 17. Using the principle of an H-type chimney, the exhaust window is designed to always have negative pressure regardless of the direction of the outside air. The wind capture opening installed on the top floor is a backflow prevention window designed with a streamlined ventilation path to minimize its pressure drop. In addition, insulation panels instead of glass are used for a higher heat-insulating capacity when the ventilation window is closed.

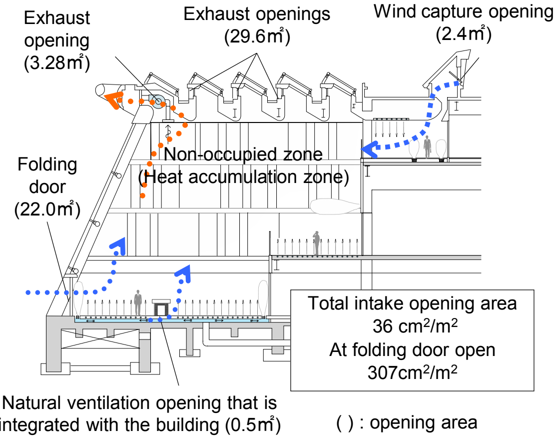


Fig. 13 SINGLE-SIDED VENTILATION PRINCIPLE

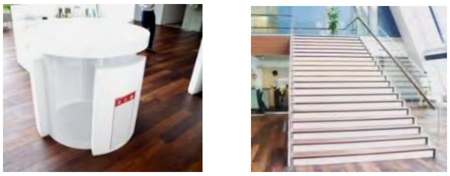


Fig. 14 NATURAL VENTILATION OPENING THAT IS INTEGRATED WITH THE BUILDING

Table. 4 DIMENSIONS AND CAPACITY OF COMPONENTS

Parameter	Value
Type (As per SOTAR)	Guiding
Free opening area	2.4 m²
Discharge Coefficient (Cd)	0.6
Overall Dimensions (1 window)	1.2m x 1.6m
Porosity (A_w/A_f)	3.1 %
Q (@ Vel = / ΔP =1Pa C_d=0.6)	1.85 m3/s

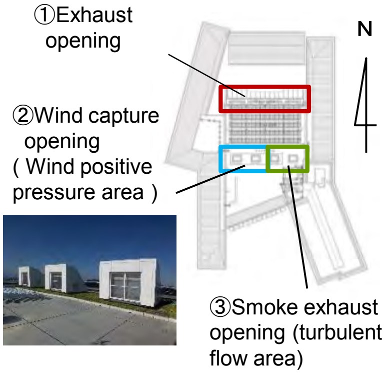


Fig. 15 RF SITE PLAN

Fig. 16 ATRIUM LOUNGE WITH OPEN FOLDING DOOR

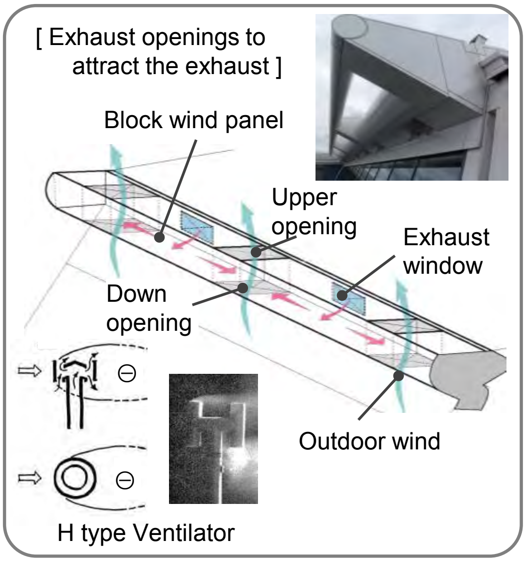


Fig. 17 SCHEMATIC DIAGRAM OF EXHAUST OPENING

5. Control Strategy

5.1 Control Strategy Overview

The control strategy for the ventilation system is largely based on the actuation of the high-level automated openings. However, all ventilation openings can be manually operated and their usage relies on the occupants' perception of the internal environment. Figure 18 presents the control strategy flowchart. Table 5 lists the controlling parameters.

Table. 5 CONDITIONS FOR OPERATING THE NATURAL VENTILATION OPENINGS

Parameter	Conditions
Enthalpy	Outdoor enthalpy < Room enthalpy
Zone Temperature	External Temperature ≦ Lowest Zone Temperature in Atrium lounge
External Temperature	15° C ≦ External Temperature
External Dew point	External Dew point ≦ 20° C
External Wind	Wind Velocity < 10 m/s
Rain	No Rain
Others	AHU operate in cooling mode

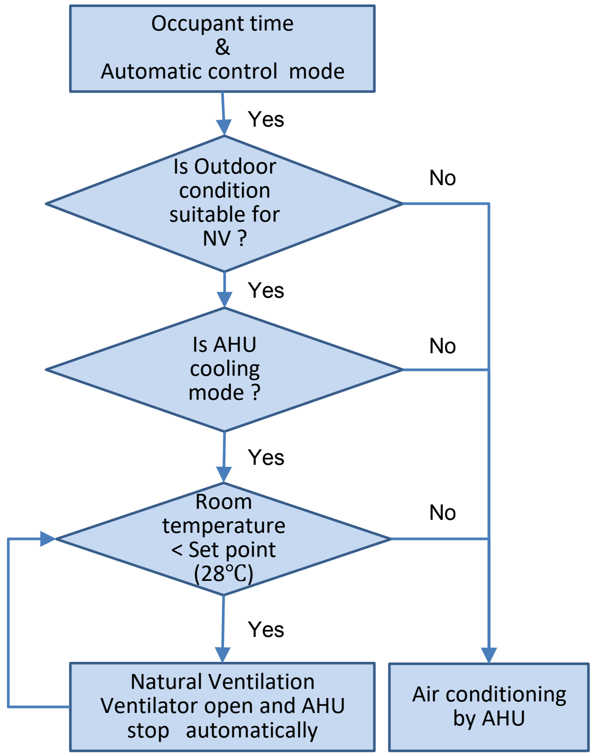


Fig. 18 AUTOMATED VENTILATOR AND AHU CONTROL FLOWCHART

5.2 Control Strategy Description

It is assumed that natural ventilation will be used in the spring (April to June), early summer, and fall (from October to November). During this period, the ventilation opening is operated automatically.
Under automatic control conditions, hybrid ventilation is also possible, as shown in Figure 19. The ceiling radiating panels can be partially operated and it is possible to operate them in combination with the natural ventilation. However, the radiation panel is controlled by a dew condensation sensor because of the risk of dew condensation due to the humidity of the outside air, and it is operated on the safety side. During actual operations, the air conditioners and the natural ventilation are operated by considering energy conservation. When the room temperature reaches 28 ° C, the system automatically switches to room temperature control using the air conditioning equipment.

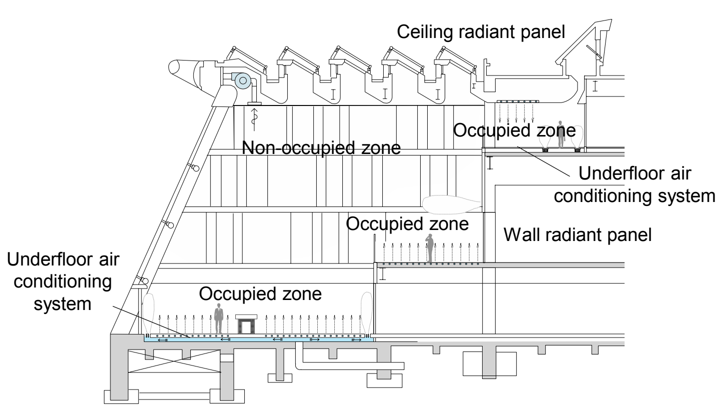


Fig. 19 AIR CONDITIONING FOR OCCUPIED ZONE OF ATRIUM

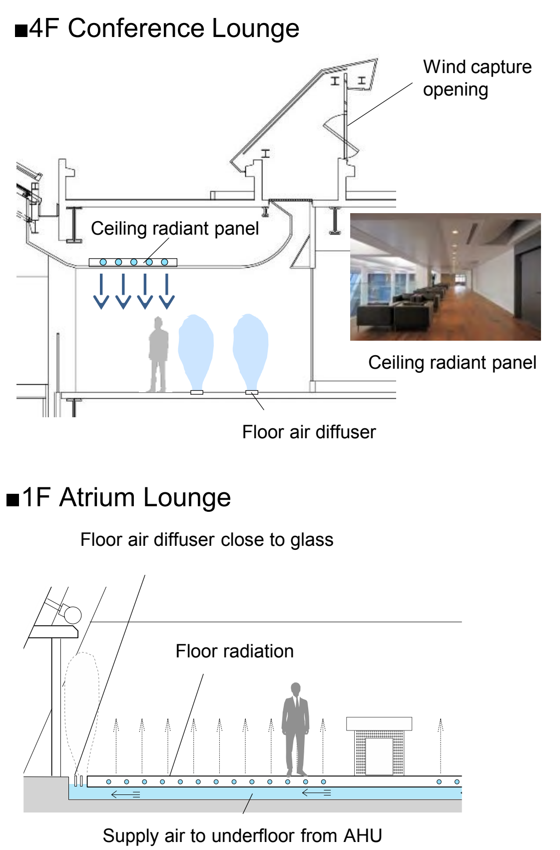


Fig. 20 1F & 4F AIR CONDITIONING SYSTEM

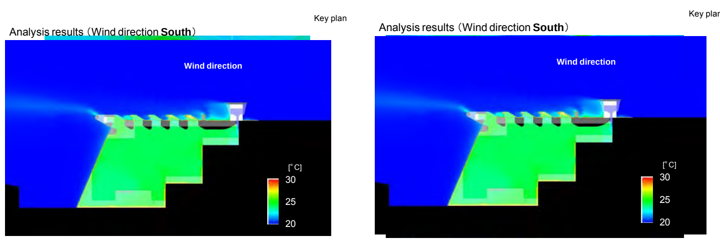
6. Design Simulation

6.1 Summary

As part of the design scope, various tools were used at different stages to evaluate the performance and assist in the specification of the equipment and the components. The code and software used was the BEST program, an integrated energy simulation tool for buildings; MEP software was used for thermal analysis and STREAM software was used for airflow modeling. Table 6 highlights the tools that were utilized at each stage of the project and Table 7 summarises the target design performance criteria. Figure 21 shows the simulation results of the concept design stage. For case (a), it can be seen that the indoor thermal environment of the 4th floor is deteriorating due to the solar radiation heat from the glass. On the other hand, this confirms that the thermal environment remains in the comfort zone for the occupied area by performing efficient exhaust heating and cooling by natural ventilation. In the detailed design stage, a CFD analysis was performed with the aim of optimizing the detailed shape of the ventilation opening. (Figures 22, 23)

Table. 6 SIMULATION TOOLS USED IN THE DESIGN STAGE

Stage	Tool	Function
Scope Development	CASBEE	Define Environmental Criteria
Concept Design	Air conditioning heat load calculation software / The BEST program CFD/STREAM	Initial Overheating Check
Detailed Design	CFD / STREAM	Thermal Analysis, Loads & ACR



(a) NO VENTILATION **(b)** NATURAL VENTILATION

Fig. 21 CONCEPT DESIGN STAGE SIMULATION: COMPARISON OF INDOOR THERMAL ENVIRONMENT FOR NATURAL VENTILATION

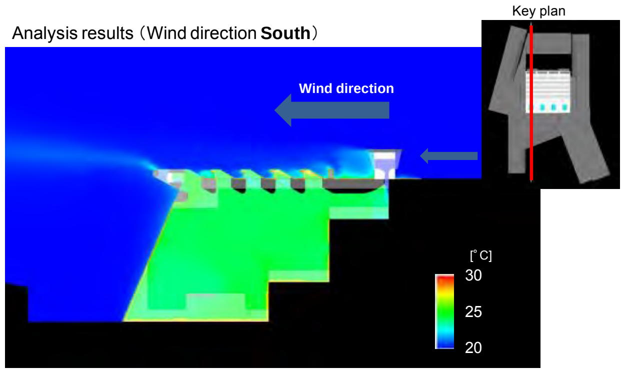


Fig. 22 DETAIL DESIGN STAGE SIMULATION: INDOOR THERMAL ENVIRONMENT FOR NATURAL VENTILATION

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Middle Season External Temp	15～26°C
T_z , Middle Season Operative Temp	26°C
Overheating criteria	T_z < 28°C for 99% hr_{occ}
Min IAQ air supply rate	8.5 ls^{-1} /pers
Noise Level Rating	NC45

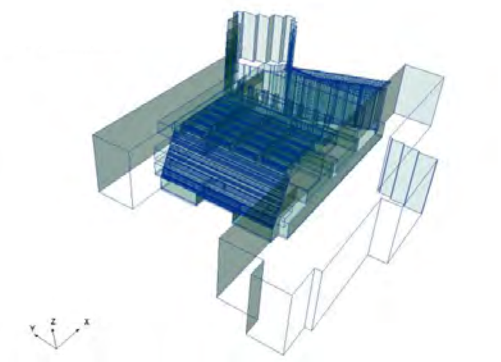


Fig. 20 SIMULATION MODEL FOR THE CONCEPT DESIGN STAGE.

Table. 8 SIMULATION CONDITIONS FOR THE CONCEPT DESIGN STAGE

Simulatin Condition	Value
External Temp	20°C
External Window	South wind 1.0m/s (height 6.5m)
Date	Sept.23 12:00
Air conditioning	No operation
Natural ventilation openings	Open

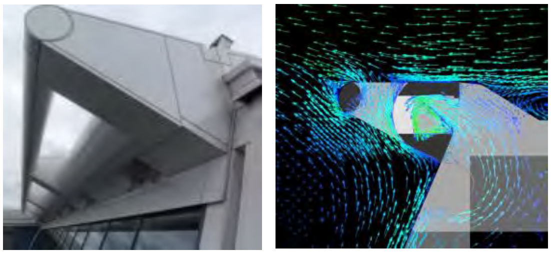


Fig. 23 DETAIL DESIGN STAGE SIMULATION: AIR FLOW OF EXHAUST OPENING

7. Performance Evaluation

7.1 Ventilation Rates

For natural ventilation, the amount of ventilation was estimated based on the room load processed by the cooling coil of the air conditioner in 2011 and taking into account the indoor-outdoor temperature differences for the same thermal load in 2013. As a result, the average ventilation volume was 14,000 CMH, which was 1.6 ACR. Because the target space is relatively large, the values for the ventilation are relatively small.

7.2 Internal Temperatures

The internal air temperature was measured and recorded in all internal spaces since 2011. The number of occupied hours when the indoor temperature exceeds a threshold value is commonly used as an indicator of overheating.

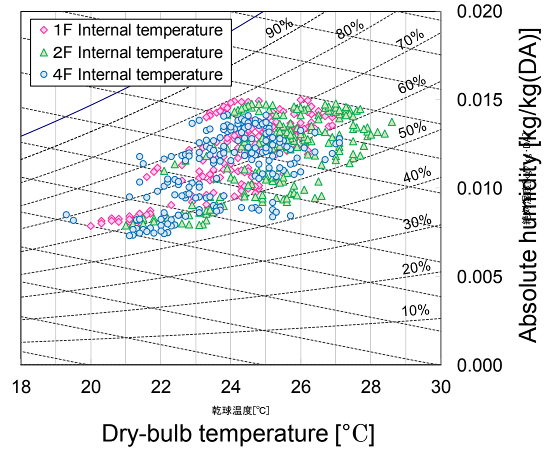
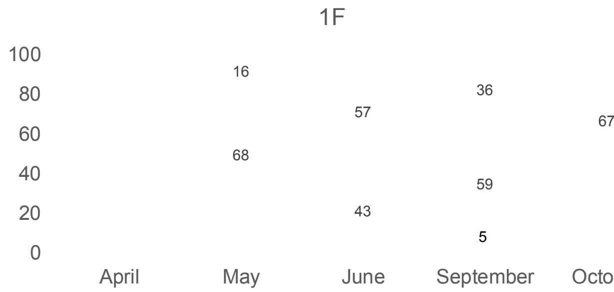


Fig. 24 PERCENTAGE OF HOURS EXCEEDING THRESHOLD VALUES FOR INTERNAL TEMPERATURES IN THE ATRIUM LOUNGE DURING 2013

7.3 Thermal Comfort

Figure 24 shows the temperature and humidity conditions of the roo during natural ventilation. The psychometric chart indicates that the roo temperate was within the comfortable range for most of the time.



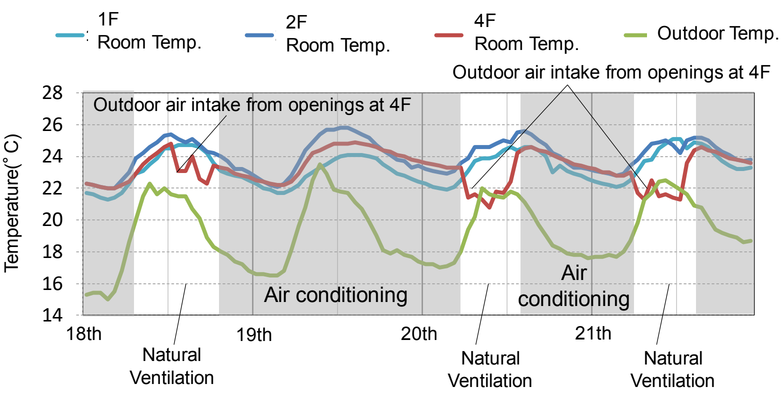
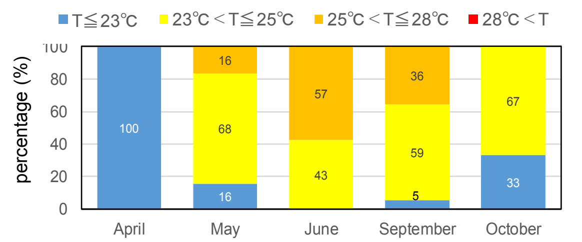
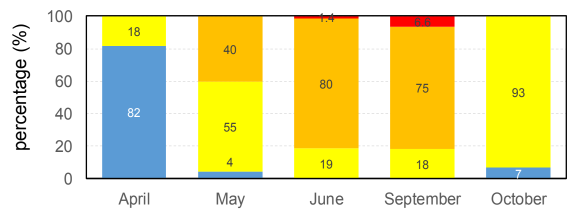


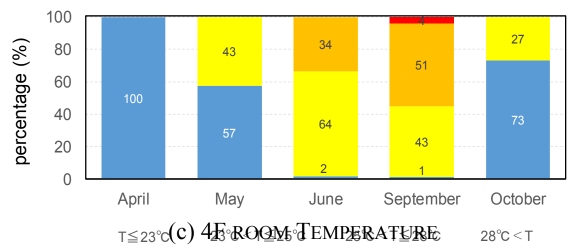
Fig. 25 4F ROOM TEMPERATURE FOR NATURAL VENTILATION IN MAY 2011



(a) 1F ROOM TEMPERATURE



(b) 2F ROOM TEMPERATURE



(c) 4F ROOM TEMPERATURE

Fig. 26 PERCENTAGE OF HOURS ABOVE THRESHOLD VALUES FOR INTERNAL TEMPERATURES AT NATURAL VENTILATION DURING 2013

7.4 Occupancy Profiles

Figure 27 shows the total number of people using the facility starting with the April 2011 opening. A total of 29,384 people attended training events (including day trips) in a year and the number of guests included 13,330 people. The monthly average number of guests was 1,110. The occupancy rate for a training facility is relatively high because day-long training events were included. Lectures and training events previously held at the hotel were held at NEXUS HAYAMA; therefore, the occupancy rate is higher than assumed.

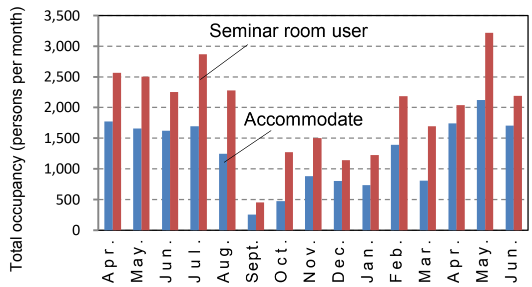


Fig. 27 Total occupancy per month from 2011 to 2012

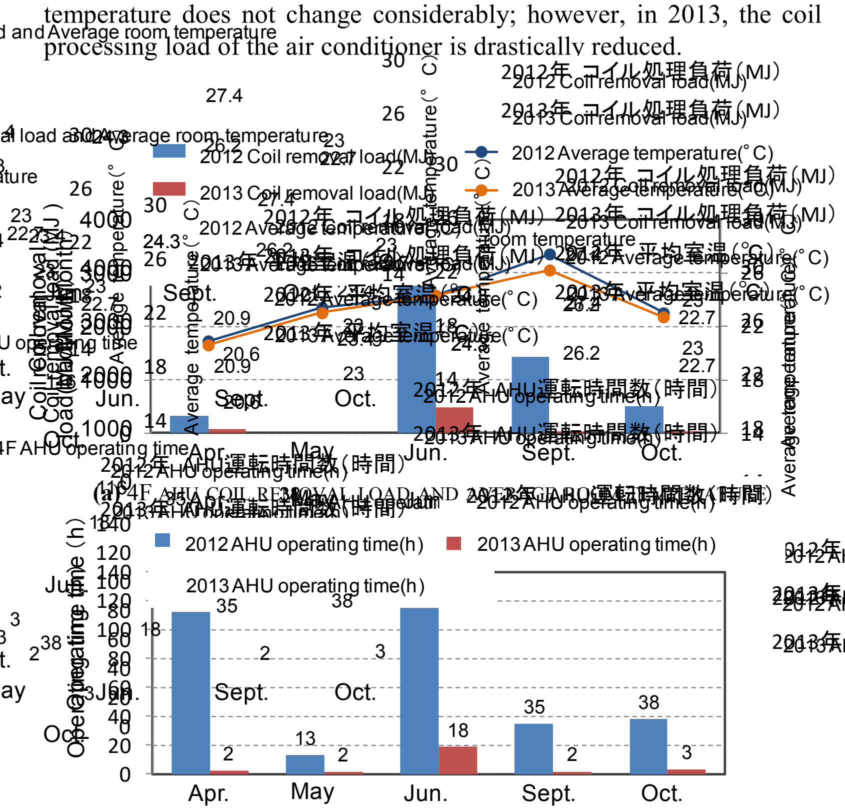
7.6 Natural Ventilation Operating Time

Table 10 shows the changes in the operating times for natural ventilation and use of the air conditioner in the atrium lounge. In 2011 and 2012, mechanical air-conditioning was mainly used based on the safety considerations by the operator. However, after consultations between the designer, the owner, and the operator, the operation changed to the use of natural ventilation after 2013.

By experiencing the comfort of the indoor environment during natural ventilation and by manually opening the natural ventilation window, the operator gained an understanding of the system. A comparison of the results for 2012 and 2013 in Figure 28 indicates that the average room temperature does not change considerably; however, in 2013, the coil processing load of the air conditioner is drastically reduced.

Table. 10 Changes in the operating times for natural ventilation (NV) and AHU in the atrium lounge

	2011	2012	2013	2014	2015
NV operating time [h/a]	102	146	816	680	1282
AHU operating time [h/a]	1641	467	177	98	128



(a) 4F AHU coil removal load and average room temperature

(b) 4F AHU operating time

Fig. 28 Comparison of the environmental control using natural ventilation in 2013 and using AHU in 2012

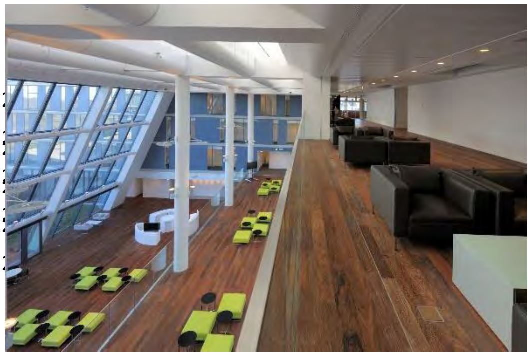


Fig. 29 4F Conference lounge

8. Lessons Learned

8.1 Summary

At the time of design, particular attention was paid to the arrangement and shape of the ventilation openings because the outside wind is relatively strong. The simulations were not sufficient to optimize the shape of the wind capture openings, which introduce the outside air from the roof, and a local wind environment survey and a field experiment at the site were necessary. Due to the building's location, the air intakes had to be designed to prevent the entry of insects and birds. The 1F floor window is limited to partial use because it was not designed with a screen door. The shape and control method of the ventilation opening is an important design point.

8.2 Detailed list of lessons learned

Table. 11 KEY LESSONS LEARNED FOR DESIGN AND CONSTRUCTION

Item	Lesson	Importance
1 Operation of ventilation window	In order to facilitate the operation, an automatic or electromotive control is used by stoppage of the central monitoring is adopted. It is preferable in terms of operation to divide the ventilation window into several systems so that some windows can be closed at the operational stage.	Better
2 Risk of overheating	We planned to introduce outside air directly to the top floor using the wind extraction windows and we created an air flow plan to collect heat sinks in the non-occupied zone and exhaust the heat. This system was evaluated highly by the owner.	Better
3 Window openings	Regarding ventilation windows, it is important to install a screen door in the opening to prevent sounds and the invasion of insects. Securing a ventilation path (cooling & heating pit) that can be opened regardless of the outside conditions was also effective. However, consideration must be given to air quality and pressure loss.	Very Important
4 Window specification	Using glass with a high insulation value and solar shielding performance, we installed a louver with a solar heat collection tube on top of the top light to reduce the solar radiation load.	Very Important

Table. 12 KEY LESSONS LEARNED FOR OPERATION / POST OCCUPANCY

Item	Lesson	Importance
1 Operating method	Although it is desirable that the control method for the ventilation window reduces operational problems by automatic control, it is important to meet with the operator and adjust the controls so they are suitable for a particular building.	Very Important
2 Screen door	Because we did not have a screen door at the folding door, there was a problem with insects entering the atrium at night.	Very Important

9. References & Key Contacts

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9.2 Key Contacts

Table. 13 KEY PROJECT CONTACTS

Company	Role	Contact
Nihon Sekkei	Project Engineers	Yoshihide Yamamoto yamamoto-y@nihonsekkei.co.jp +815031396927
Nihon Sekkei	Project Engineers	Masato Sasaki sasaki-ma@nihonsekkei.co.jp +815031396764
Nihon Sekkei	Project Architect	Masashi Takeda takeda-m@nihonsekkei.co.jp +815031397417

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Key Features & Climate

IEA EBC Annex 62 The IEA project on ventilative cooling

1 Introduction

GRAND FRONT OSAKA (GFO) was completed by developing 7ha, a part of the container yard site (in total 24 ha), which was regarded as the prior development area (Phase 1). GFO is located to the north the Osaka station that is the biggest centre the transportation in the west part of Japan. It is the big project that is expected to contribute greatly to economic growth in the western region of Japan, which creates a fascinating environment by collecting advanced city functions such as a base of intelligence and creation ("Knowledge Capital"). The main theme of GFO is "a comfortable town with low environmental load" where the movement of the wind, greenery, water, and heat were carefully designed to increase the contact of people with nature. It was designed based on three concepts, i.e., 1) a town where the wind is perceived, 2) a town where water and green are impressive, 3) visualization of the design performance and intent ("Mieruka") in all over the town. The natural ventilation design introduced in this case study is also one of the main strategies to achieve these concepts.

Fig.1 External Appearance of GRAND FRONT OSAKA

Table.1 Key Information about Building

Location	Osaka, Japan
Building Type	Office, shop, hotel
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Urban
Ventilative Cooling Strategy	Nutural/Hybrid
Year of Completion	2013
Floor Area (m^2)	295,000 (North bld.) 99,000 (Tower B)
Shape Coefficient (1/m)	6.3 (North bld.) 8.3 (Tower B)
Openable Area to Floor Area Ratio (%)	0.5 (Tower B)
Window to Wall Ratio (%)	70 (Tower B)
Sensible Internal Load (W/m^2)	35
STA KPI (Measured?)	-
Climate Zone (KG) (words?)	-
No. of Days with T_e max > 25	123
Cooling Season Humidity	high
Heating Degree days (Kd)	884

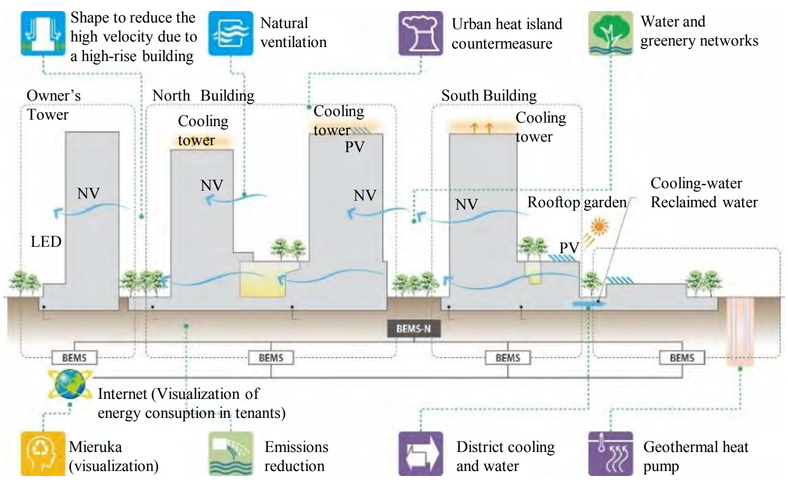


Fig.2 Summary of Environmental Planning Concept

1.2 Local Climate

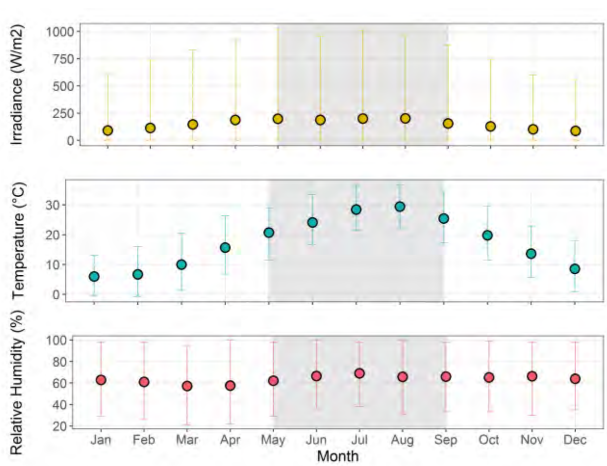


Fig.3 Mean, maximum and minimum external conditions in Cork Airport using TMY3 (cooling season shown shaded)

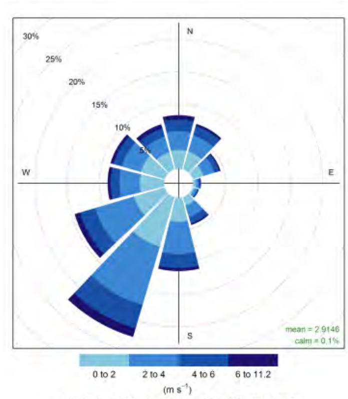


Fig.4 Windrose for Osaka

2. Building Information

2.1 Description

GFO is a vast building complex consisting of the Knowledge Capital, commercial shops, office rooms, hotel, condominiums, and so on, of which grand opening was 26th April, 2013. With a basis of "a system of the water, greenery, and bustle", it gives importance to "planning for enjoyable town walk", "design and functions harmonised with the whole town", and "the whole town is eco-friendly". GFO town has four blocks. The whole town consists of "Umekita Plaza" that has a large waterscape cascade and a symbolic building, "Umekita SHIP", three high-rise towers (Tower A, B, and C) including commercial shops and office rooms, and another high-rise condominium. This case study introduces Tower B that is mainly used as a multi-tenant office building where one floor is assumed to be rent by six tenants.

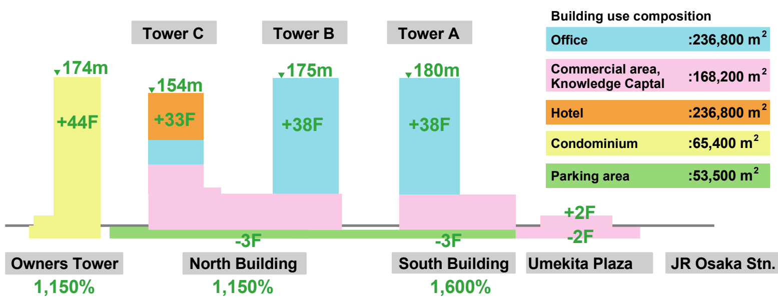
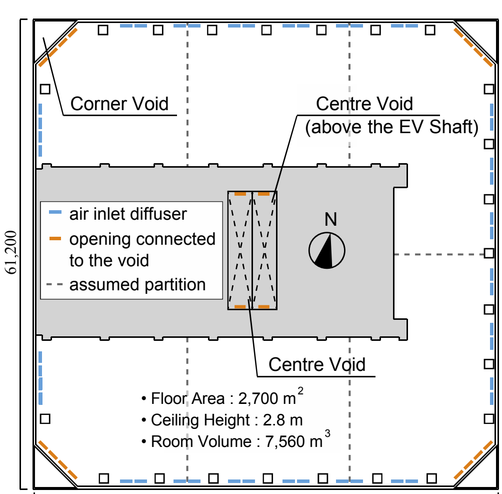


Fig.6 SUMMARY OF FLOOR AREA IN THE BUILDING COMPLEX GFO

Fig.7 BLOCK PLANNNING IN GRAND FRONT OSAKA



*Slits are also provided at the ceiling to allow the air to flow into the centre void through plenum space.

Fig.8 TYPICAL FLOOR PLAN OF TOWER B

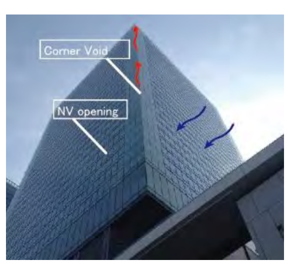


Fig.9 CORNER VOIDS AND AIR INTAKE SLITS IN THE WALL

Fig.10 NV INLET DIFFUSER

Table.2 BUILDING PROPERTIES (TOWER B)

Property	Unit	Value
Occupant density	m^2/p	10
Hours of occupancy	h/week	50
Sensible Internal Load	(W/m^2)	35
Window U-value	W/m^2K	1.7
Window g-value	(-)	0.33
Wall U-value	W/m^2K	0.9
Roof U-value	W/m^2K	0.45
Floor U-value	W/m^2K	1.7
Q-value (from Japan)	$(W/m^2)/K$	1.4
Thermal Mass (ISO 13790)	-	-
Window to Wall Ratio	%	70
Air-tightness (@50 Pa)	1/h	-
Shape Coefficient (1/m)	1/m	8.3

Table.3 DESIGN INFLUENCES

Parameter	Level of Influence
Initial Costs	⬤
Maintenance Costs	⬤
Energy costs	•
Solar Loads	•
Internal Loads	•
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	•
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	•

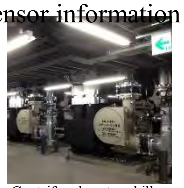
3. Energy Systems

3.1 Cooling/Heating System

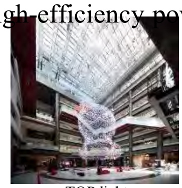
The primary HVAC equipment is installed for each town block. The ratio of electricity to gas is set at approximately 50:50 for the sake of Business Continuity Plan (BCP) by providing two kinds of infrastructure. The electric chillers with the ice thermal energy storage system are installed at the bottom floor to reduce the structural load, while all the HVAC primary equipment using gas is located at the top floor to reduce the required space for the flues. As a future treatment option, there also provided a void space to facilitate to carry the massive HVAC equipment into the building. To minimize the negative thermal impact upon its neighboring area, the exhausted heat is discharged from the top of the building through latent heat. For the same purpose, the geothermal heat utilization, exhausted heat recovery system, and the heat transportation between town blocks are adopted.

3.2 Electrical Power Supply (PV, wind turbine & Microgrid)

As a disaster-resistant building, the power receiving and transforming facilities are located higher than the inundation level, and the electrical generators are also installed at the middle floor and1 roof floor to avoid the damage from a flood. The PV panels are also provided in each town block. In the buildings, power consumption is reduced by daylighting, putting various kinds of sensor information to practical use, high-efficiency power transforming facilities, and so on.


Centrifugal water chiller (North and South B3F)


Extra high voltage transformer (North and South 8F)


TOP light (Knowledge Plaza)

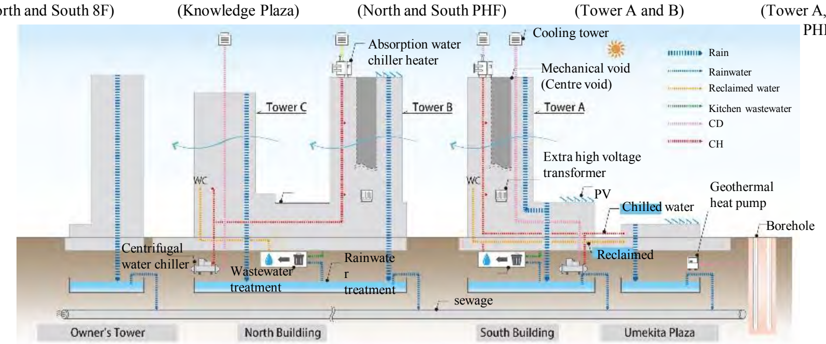

Absorption water chiller voiler (North and South PHF)


Mechanical (centre) void (Tower A and B)


Cooling Tower (Tower A,B and C PHF)


Geothermal heat pump (Umekita Plaza)


Natural Ventilation - Corner Void (Tower B)



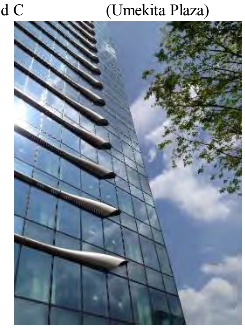

Natural Ventilation – Air intake (Tower A)

Fig.11 ENERGY SYSTEM IN GRAND FRONT OSAKA

	Condominium (Owners Tower)	North Building	South Building	Umekita Plaza
HVAC	**AIR-CONDITINING FACILITIES** **• Common Area** · Air-source heat pump packaged · air-conditioner **• Residences** · Residential room air-conditioner · Bathroom heater with ventilator and dryer	**PRIMARY HVAC EQUIPMENT** **• Chilled water (12,000 RT in total)** · Inverter-controlled centrifugal water chiller :1,000 RT × 2 · Screw liquid chiller : 590 RT×1 · Brine centrifugal chiller : 750 RT×1 · Ice-based thermal energy storage system : 3900 RTH×2、(melting time 5.2 h) · Water-cooled modular chiller (570RT×2) · Absorption water chiller boiler (730RT×6) **• Hot water (20,200 kW)** · Absorption water chiller boiler (1,940kW×6) · Hot water heater (930kW×5 + 1,000kW×3) **AIR-CONDITINING FACILITIES** **• Office Room** · Outside air conditioner (VAV) + distributed air-handling unit (VAV) **• Commercial Area** · Outside air conditioner (VAV) + fan coil unit	**PRIMARY HVAC EQUIPMENT** **• Chilled water : 7,000 RT in total)** · Inverter-controlled centrifugal water chiller :750 RT × 2 · Screw liquid chiller : 460 RT×2 · Brine centrifugal chiller : 550RT×1 · Ice-based thermal energy storage system : 2750 RTH×2, (melting time 5.0 h) · Absorption water chiller boiler (460RT×6) **• Hot water (12,500 kW)** · Absorption water chiller boiler (1,530kW×6) · Hot water heater (930kW×3) **AIR-CONDITINING FACILITIES** **• Office Room** · Outside air conditioner (VAV) + distributed air-handling unit (VAV) **• Commercial Area** · Outside air conditioner (VAV) + fan coil unit	**PRIMARY HVAC EQUIPMENT** **• Chilled water : 600 RT in total)** · Screw liquid chiller : 250 RT×1 · Geothermal heat pump : 210 kW×1 · Absorption water chiller boiler (660 kW×1) **• Hot water (1,300 kW)** · Absorption water chiller boiler (210kW×1) · Absorption water chiller boiler (660 kW×1) · Hot water heater (460kW×1) **AIR-CONDITINING FACILITIES** **• Commercial Area** · Outside air conditioner (VAV) + fan coil unit **• Hall** · Outside air conditioner (VAV) + fan coil unit · Air handling unit + Radiant cooling/heating
SANITATION	**WATER SOURCE** · Potable water **WATER SUPPLY SYSTEM** · Pressurised water supply **• Water tank** · 219 m3 (potable water) **•Hot water supply** · Decentralised gas water heating	**WATER SOURCE** · Potable water, storm water, regenerated water from kitchen wastewater. **WATER SUPPLY SYSTEM** · Pressurised water supply (for lower floors) · Gravitational water supply (for upper floors) **• Water tank** · 310 m3×2 (potable), 1,200 m3 (non-potable), 550 m3 (make-up water for cooling tower) **Preliminary treatment for sewerage protection** 450 m3/day (regenerated for non-potable water)	**WATER SOURCE** · Potable water, storm water, regenerated water from kitchen wastewater. **WATER SUPPLY SYSTEM** · Pressurised water supply (for lower floors) · Gravitational water supply (for upper floors) **• Water tank** · 180 m3×2 (potable), 720 m3 (non-potable), 315 m3 (make-up water for cooling tower) **Preliminary treatment for sewerage protection** 375 m3/day (regenerated for non-potable water)	**WATER SOURCE** · Potable water, storm water, regenerated water from kitchen wastewater. **WATER SUPPLY SYSTEM** · Pressurised water supply (for lower floors) · Gravitational water supply (for upper floors) **• Water tank** · 50 m3×2 (potable), 450 m3 (non-potable), 315 m3 (make-up water for cooling tower) **Preliminary treatment for sewerage protection** 100 m3/day (regenerated for non-potable water)

Fig.12 ENERGY SYSTEM IN GRAND FRONT OSAKA

4. Ventilative Cooling

4.1 Principles

In each floor, the natural ventilation openings of which total area is 14 m² are installed. In order to deal with the partitions between tenants, four voids at the corner (corner void) and a void in the core region (first centre void) are provided. At four floors in the upper storey, the flow path connecting the first centre void is closed to prevent the backflow from the void into the office rooms and the second centre void was provided instead.

4.2 Components

• Inlet diffuser

The interior region requires the cold thermal energy by natural ventilation due to the internal heat generation (cooling load). In this building, the inflowing air is expected to flow along the ceiling and reach far inside the room from the inlet diffuser by Coanda effect. Inside the inlet diffuser, a balance-type flap is provided to prevent the blast from entering.

• Exhaust opening

Considering the pressure difference caused by buoyancy, the area and number of the openings between the office room and corner voids were made large in the upper floors. This was intended to reduce the differences in natural ventilation rate among floors.

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Enhancing & Guiding
Free opening area (1 floor)	14 m²
Discharge Coefficient (Cd)	0.412~0.536
Overall Dimensions (1 NV inlet opening)	0.15m × 0.9m
Porosity	0.5%
Δp-Q characteristics	See Fig.24

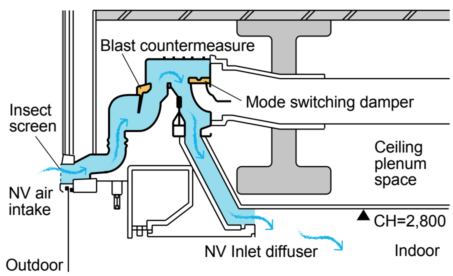
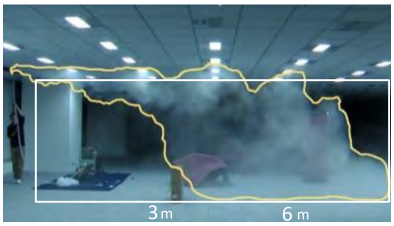


Fig.13 SCHEMATIC OF THE NV INLET DIFFUSER



Mean external wind speed : 1.2m/s
Wind direction : East
ACH (design value) : 1.5 h^{-1}

Fig.14 VISUALIZED NV INLET FLOW

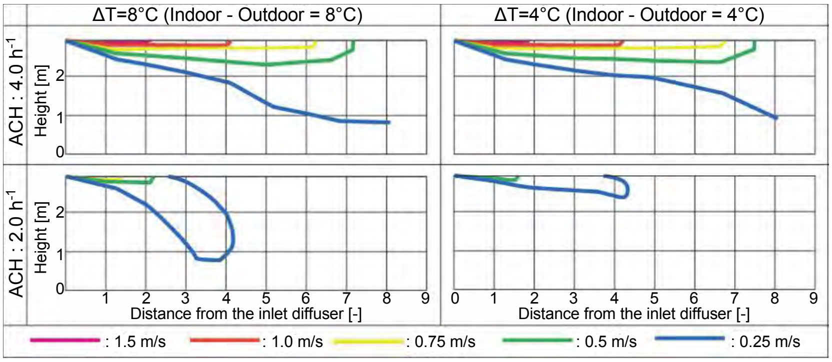


Fig.15 VELOCITY CONTOUR LINES AROUND NV INLET DIFFUSER

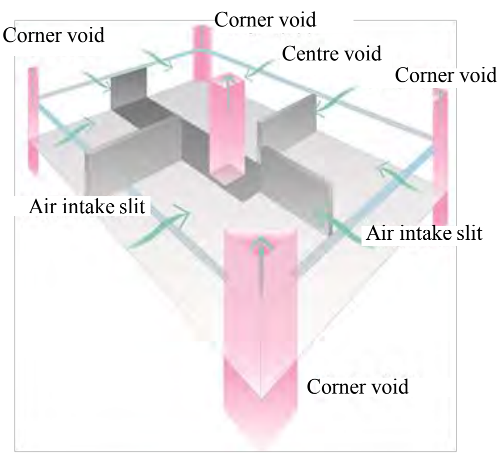


Fig. 16 SCHEMATIC OF NV AIR PATH THROUGH AN OFFICE ROOM

Location	Floor	Opening Area [m²]	Number	Total Opening Area[m²]	Discharge Coefficient [-]
Centre (1)	12～33	2 ～ 9.6	2	4 ～ 19.2	Louver (porosity 50%)
Centre (2)	34 ～ 37	9.6	2	19.2	Louver (porosity 50%)
Corner	24 ～ 33	0.654	4	2.616	0.536
	16 ～ 23	0.524	4	2.096	0.517
	13 ～ 15	0.524	3	1.572	
	12	0.524	2	1.048	
Slit	12 ～ 37	0.133	42 ～ 50	5.586 ～ 6.650	0.412

Fig. 17 PROPERTIES OF THE OPENINGS USED IN NATURAL VENTILATION SYSTEM

5. Control Strategy

5.1 Control Strategy Overview

Since this is a multi-tenant office building where complicated selection of HVAC operation mode is not preferable, the HVAC system was designed to allow occupants (tenant) to choose one from two modes, i.e., “Air-conditioning” and “Natural ventilation”. While the comfortable temperature is maintained in the former mode, it becomes free-running temperature in the latter when the outdoor condition meets the criteria to open NV openings.

5.2 Control Strategy Description

When the “Air-conditioning mode” is chosen, the actual detailed control is automatically selected among three operation modes depending on outdoor air condition to achieve energy saving, i.e., “Hybrid Ventilation (HV)” (NV + air-conditioning), “Outdoor-Air Cooling (OAC)” (Ventilative cooling by the mechanical fan), and “Air-Conditioning”. The night-purge ventilation operation by the mechanical fan is also permitted in this building. As for the criteria to open NV openings, the maximum relative humidity is considered. Here, the minimum temperature is arranged as well to reduce the cold draught due to natural ventilation. For details, see Table 5. However, these set values regarding the criteria can be flexibly changed depending on the tenant.

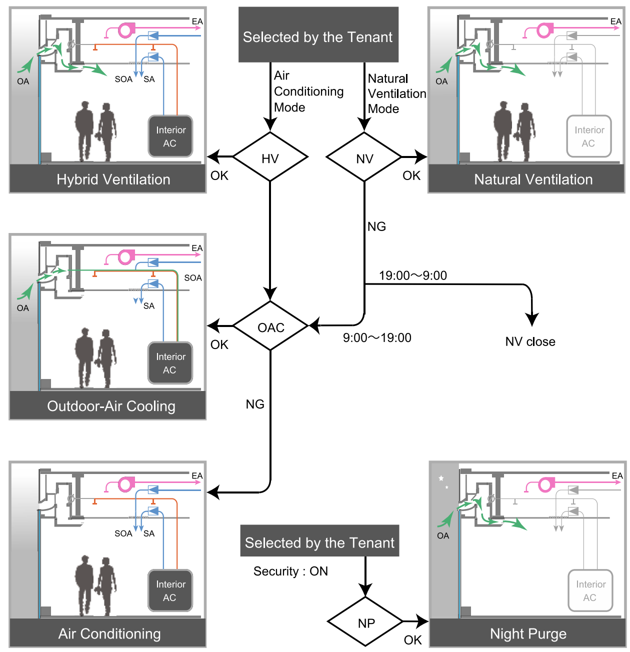


Fig. 18 Automated ventilator and AHU control flowchart

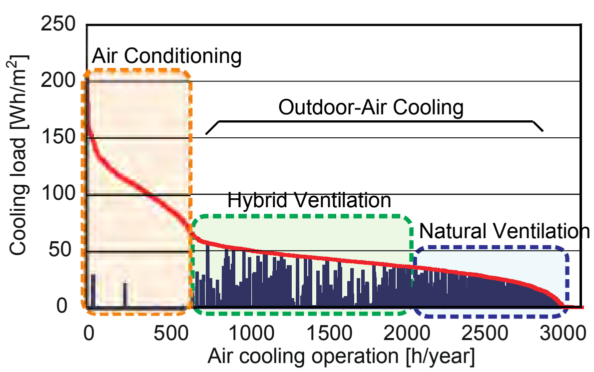


Fig. 19 Cooling load duration curve

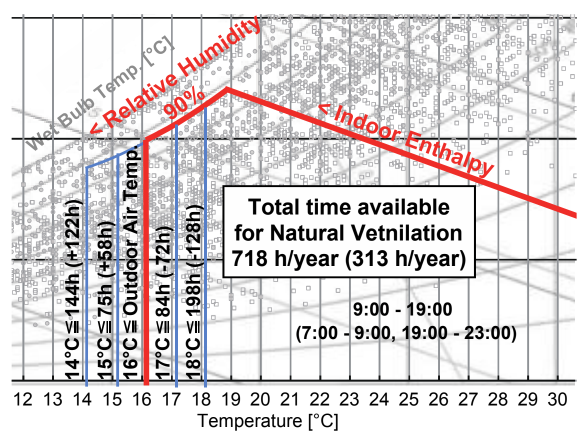


Fig. 20 Psychrometric chart (outdoor air)

Table. 5 Conditions for operating the natural ventilation openings

Parameter	Conditions			
	Natural Ventilation (NV)	Hybrid Ventilation (HV)	Outdoor Air Cooling (OAC)	Night Purge
Enthalpy	Outdoor < Indoor			NA
Zone Temperature	NA			26° C≦
External Temperature	10~20° C≦ (By occupants)	16° C≦	10° C≦	10° C≦ Outdoor<Indoor
External Relative humidity	≦ 90%RH			
External Dew point	NA		7.8° C≦	NA
External Wind	< 15 m/s			
Rain	No Rain			
Others	AHU operate in cooling mode			

6. Design Simulation

6.1 Summary

Since the Tower A, the nearest building to the station, was expected to be rented by small tenants, a central-core type plan was adopted because relatively small room depth was desirable. On the other hand, the target of the Tower B was larger tenant, and here an eccentric-core type was selected so that the room depth could be large enough. In order to predict the differences in natural ventilation performance due to the core-type plan and to decide the natural ventilation type, CFD simulations were performed under the south-west wind condition (prevailing wind direction) in the concept design stage. In the case where the wind-induced natural ventilation (cross-ventilation) was applied to all three towers, Tower A is well ventilated because NV openings are sufficiently provided for both windward and leeward façade. In Tower B and C, however, the indoor temperature tends to become high because of the position of the core and the effect of the surrounding buildings. Therefore, in these two towers, buoyancy-induced NV system by voids was adopted together with the wind-induced NV system aiming for stable NV performance. For reverification, another CFD calculation simulating this case was performed as well, and this NV system was finally adopted.

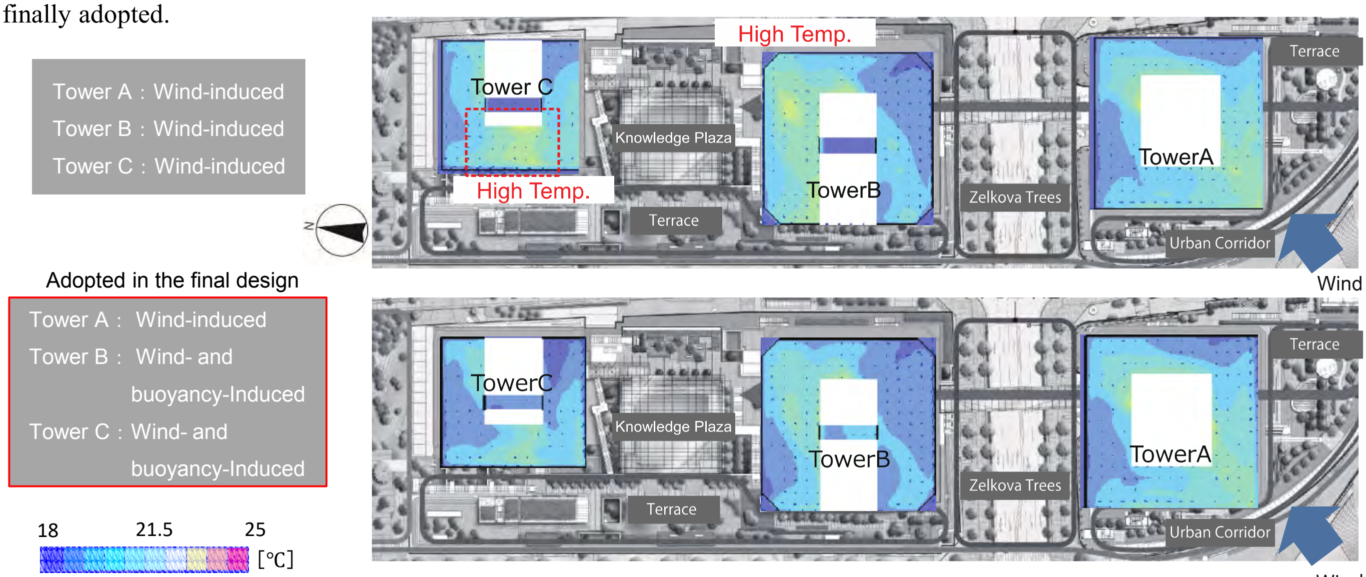


Fig. 21 TEMPERATURE DISTRIBUTION OBTAINED FROM CFD IN THE CONCEPT DESIGN STAGE

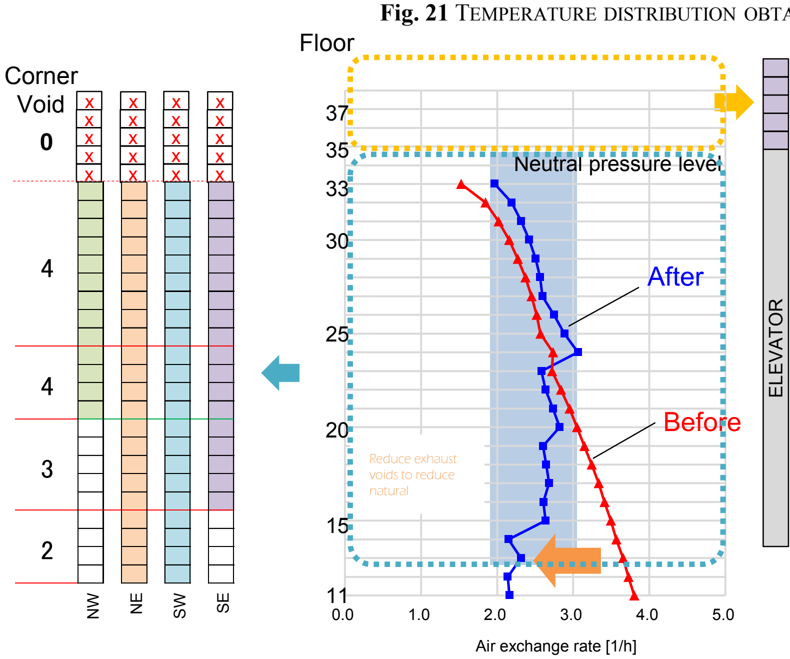


Fig. 22 CONCEPT DESIGN STAGE SIMULATION (FLOW NETWORK CALCULATION)

In addition to the stable natural ventilation (void installation), it was aimed to reduce the differences in natural ventilation rate among floors because this building is a multi-tenant office building. This was achieved by making differences in the opening area and the number of corner voids among floors. In the concept design stage, therefore, the flow network simulation was also performed. According to this study, in the upper four floors, it was decided to close the flow paths to the corner voids and the first centre void to prevent the backflow through the voids because these floors were supposed to be higher than the neutral pressure level. Instead, the second centre void was used as the natural ventilation flow path in these four floors. Due to this simulation, the undesirable variation among the floors was expected to be improved as shown in Fig.22.

7. Performance Evaluation

7.1 Natural Ventilation Opening

The flow rate through a natural ventilation opening could be estimated based on the following so-called orifice equation.

$$Q = C_D A \sqrt{\frac{2}{\rho} \Delta p}$$

Q : Flow rate [m^3/s] C_D : Discharge coefficient [-]
A : Opening Area [m^2] ρ : Air density [kg/m^3]
ΔP : Pressure drop [Pa]

The discharge coefficient was evaluated by the laboratory experiment before construction. To evaluate the total natural ventilation rate of the room, the indoor/outdoor pressure difference has been measured in the post-occupancy measurement. Each building wall had two measurement points for all four sides, and each corner void had one measurement point. Based on the result, the natural ventilation flow rate was calculated. This field measurement was carried out at three floors, i.e., the lower (GL+65 m), middle (GL+115 m), and upper floor (GL+150 m). In this field measurement, pressure differences across the openings were also measured by using a mechanical fan of the air handling unit (Fig.23), and the discharge coefficient of 0.42 was obtained for the NV opening, and 0.52 for the corner-void opening.

7.2 Ventilation Rates

The natural ventilation flow rate was calculated every one hour during the period from April 2014 to March 2015 by using one-hour-average measurement data. Here, the flow rate was also estimated while NV openings were closed based on the flow rate balance by estimating the internal pressure. A case study regarding the existence of the voids was also performed by evaluating the natural ventilation rate and its frequency (Fig.25). It found that relatively large natural ventilation rate would be stably obtained by providing the natural ventilation voids, and the system could work effectively to remove internal sensible heat load. The result that large flow rate can be obtained in the middle floor agrees with the prediction using flow network model, and this meets the design intent. In addition to the flow rate estimation based on pressure difference measurement, other methods to estimate flow rate, i.e., tracer gas technique and velocity measurement at the NV openings were also used to verify that there were no significant differences from the estimation based on pressure measurement.

Table 8 FOW RATE ESTIMATION METHODS ADOPTED IN THE FIRLD MEASUREMENT

Method		**Advantage/Disadvantage**	**Suitable for**
Pressure Difference	Estimate the flow rate using p-Q curves and pressure difference across the opening	A. Continuous measurement D. Requires p-Q curves	Field measurement under occupation
Tracer gas	Step-up constant injection or concentration decay method using CO2 to calculate local mean age of air and effective ventilation rate	A. Horizontal distribution can be known D. Trouble and labor	Experiment
Velocity	Install anemometer at every NV openings, multiply velocity by opening are	D. NV openings need to be always open during measurement	Experiment

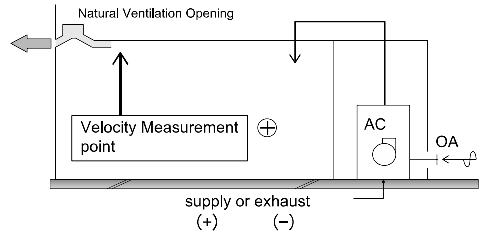


Fig. 23 ESTIMATION OF THE DISCHARGE COEFFICIENT IN THE FIELD MEASUREMENT

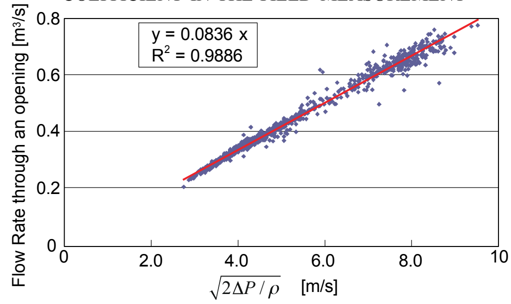


Fig. 24 ΔP-Q CHARACTERISTICS OF THE NV OPENING

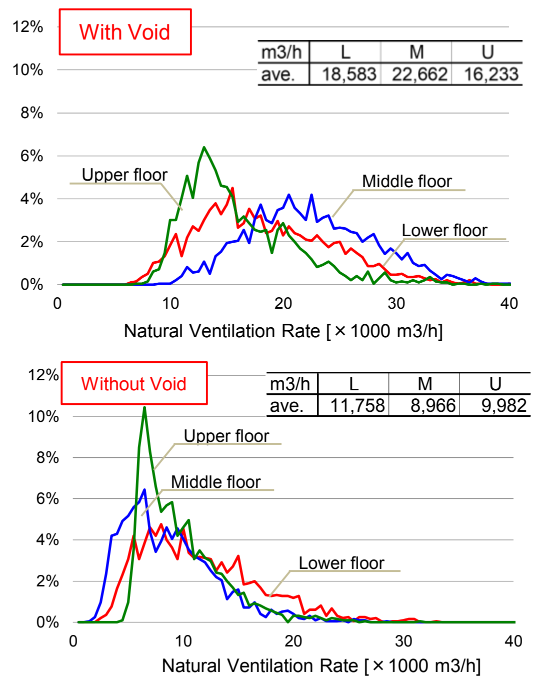


Fig. 25 HISTOGRAM OF THE NATURAL VENTILATION RATE FOR THE CASES WITH/WITHOUT THE VOIDS

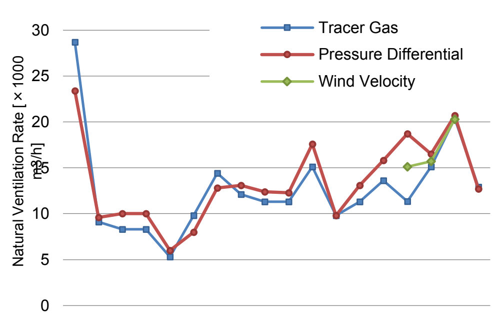


Fig. 26 NV RATE MEASURED BY THREE METHODS

7. Performance Evaluation

7.1 Natural Ventilation Opening

As a part of performance evaluation, the local mean age of air was also measured under natural ventilation operation by using CO_2 as a tracer gas. Here, the step-down method was applied and the local mean age of air (τ_p) was measured at 25 points in the room according to the following equation.

$$t_P = \int_0^{\infty} \frac{C_r(t) - C_O}{C_r(0) - C_O} dt$$

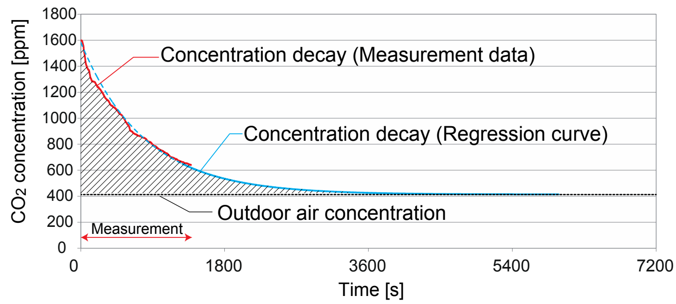


Fig. 27 Calculation of Local Mean Age of Air based on measured CO2 concentration

where, C_o is the outdoor (= inlet) concentration, and C_r is the indoor concentration as a function of time. It was calculated to evaluate the internal distribution of the fresh outdoor air. Based on the trapezoidal integration of the exponential fitting curve of the concentration decay data, τ_p was obtained at each measurement point as shown in Fig.27.

In Case 1, all the openings between the office room and corner void were closed to evaluate natural ventilation performance in horizontal cross-ventilation operation, though it was not actually-intended operation but for the comparison. In this case, τ_p becomes small in the south-west area of the room and this indicates that the fresh air reaches here quickly because it is on the windward side. On the other hand, τ_p tends to be large in the north area, which means that most part of the inflowing fresh air does not reach the north side and flows out from other NV openings. In this wind direction, the building core works as an obstacle for the cross-ventilation from south to north side.

In Case 2-1, all the openings connected to the corner void were opened, corresponding to the actual operation. In this case, the external wind direction was SSW and the velocity 3.0 m/s, which was similar meteorological condition to Case 1. The measurement result shows that in general τ_p becomes small if compared with Case 1. As for the distribution, smaller age can be observed in the south-west part due to the effect of the wind direction. In Case 2-2 where the building was exposed to the wind of low velocity, small and almost uniform age distribution was obtained. In this case, the stack effect seems to be dominant because of low wind velocity, and it is believed that the fresh air comes into the room uniformly from all the wall NV openings.

According to this performance evaluation, it could be verified that the age distribution strongly depended on the wind direction if the horizontal cross-ventilation operation was applied to this building and that the NV system could work quite well by introducing buoyancy-induced natural ventilation using corner voids even when the external wind condition was calm.

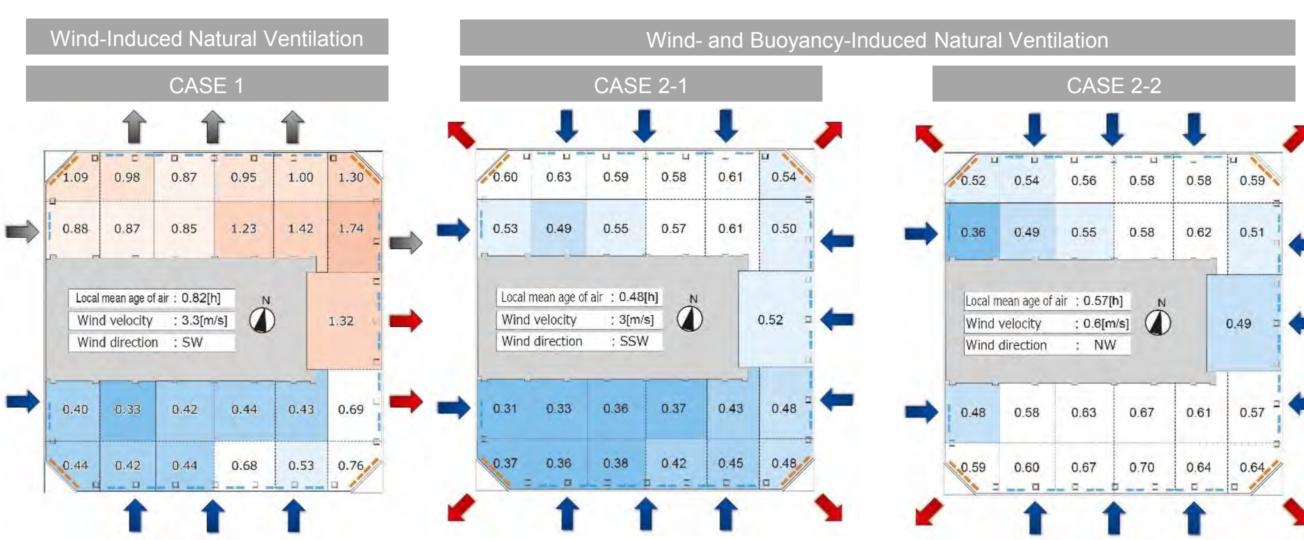
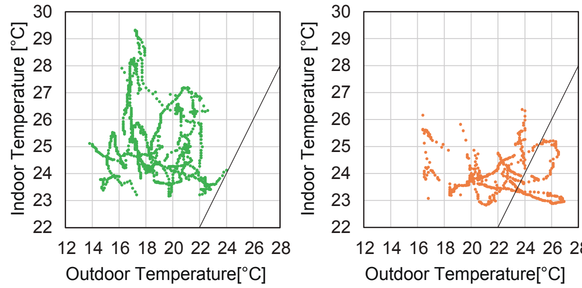


Fig. 28 Distribution of Local Mean Age of Air [h]

7. Performance Evaluation

7.4 Room Temperature

Fig. 29 presents the correlation between indoor and outdoor air temperature during 6th to 31st October 2014 for both operations of the natural ventilation and hybrid ventilation, that was measured at one tenant zone. Here, the straight line in the graph indicates the outdoor temperature is equal to indoor temperature. Under the natural ventilation operation, indoor temperature is always higher than outdoor temperature, and sometimes considerably increases depending on natural ventilation rate. On the other hand, under the operation of hybrid ventilation, no significant temperature rise can be seen because mechanical air-conditioning is also operated in addition to the natural ventilation.

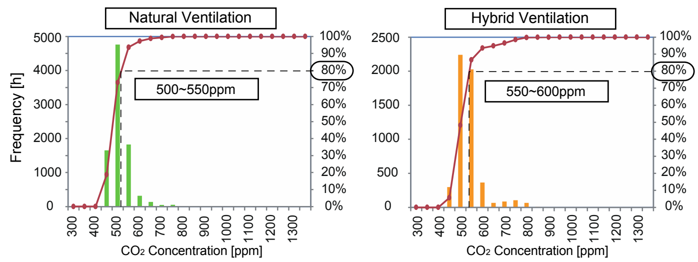


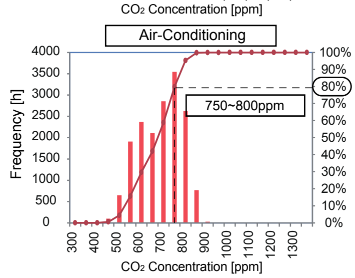
(1) Natural Ventilation (2) Hybrid Ventilation

Fig. 29 CORRELATION BETWEEN INDOOR AND OUTDOOR TEMPERATURE

7.5 CO2 Concentration

Fig.30 gives the histogram and cumulative frequency polygon of the indoor CO_2 concentration for each operation mode (AC / Hybrid Ventilation (HV) / Natural Ventilation (NV)). Here, the concentration of 80% in the cumulative frequency is also indicated just for reference. It is shown that relatively low indoor CO_2 concentration of five to six hundred ppm is observed when the natural ventilation is operated in HV and NV mode, which verifies that low concentration is stably achieved by adopting natural ventilation system.





Period : 6th to 31st Oct. 2014

Fig. 30 HISTOGRAM OF CO2 CONCENTRATION

7.6 Pollen

Since pollen could become a serious matter in spring in Japan, some tenants have declared not to operate natural ventilation to prevent it. Measuring the indoor pollen particle number, however, there observed no significant effect of natural ventilation (Fig.31). This indicates that the impression of the occupants considerably affects the NV operation.

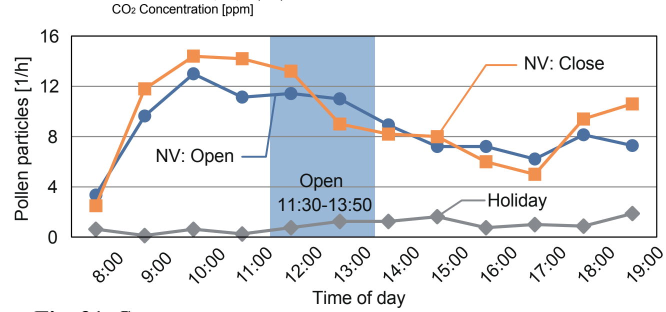
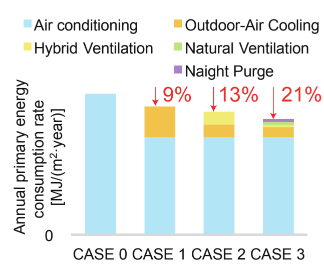


Fig. 31 CAPTURE RATE OF POLLEN PARTICLES BY POLLEN SENSOR

7.6 Energy Saving Performance

A case study simulation regarding operation mode was carried out to evaluate primary energy consumption. As expanding the use range of operation mode, i.e., the OAC, HV, NV, and night purge (NP) mode, the primary energy consumption rate becomes smaller if compared with the ordinary operation of the air-conditioning alone. In Case 3 where all operation modes are applied, the reduction rate from the ordinary air-conditioning operation becomes 21%. In this case, the NV becomes the most frequent operation mode in April, May, and October. When the climate is colder than these mid-seasons, the OAC mode can be effectively operated. Throughout the year, the percentage of the ordinary air-conditioning operation can be reduced up to 57%, and some other energy-saving mode can be applied for remaining 43 %.

	OAC	HV	NV	NP
Case 0	N/A	N/A	N/A	N/A
Case 1	●	N/A	N/A	N/A
Case 2	●	●	N/A	N/A
Case 3	●	●	●	●



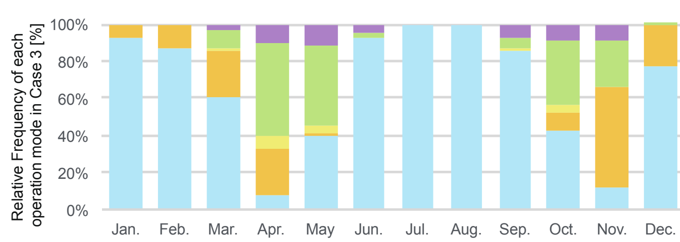


Fig. 32 COMPARISON OF ENERGY PERFORMANCE IN 4 CASES OF OPERATION STRATEGIES

8. Lessons Learned

8.1 Summary

To date, company-owned and low- to mid-rise buildings have accounted for a large part of the office buildings with natural ventilation systems, of which major reasons are as follows.

- The NV system is not suitable for providing a stable and comfortable indoor environment.
- Troubles caused by e.g., forgetting to close NV windows, NV operation under the conditions where it is not allowed.
- If applied to high-rise office buildings, excessive NV rate or indoor velocity can be observed due to high wind velocity.

Against these issues, in this example, the following measures have been taken.

- Automation of the NV opening control.
- Contrivance in detailed shape design of NV openings and its indoor terminals.
- The occupants themselves are allowed to choose the operation.

To realise more energy-efficient building, it is important that the occupants themselves act to save energy with their own mind. The system of Grand-Front-Osaka was designed based on such an idea.

8.2 Detailed list of lessons learned

Table. 12 Key Lessons Learned **Design and Construction**

Item	Lesson	Importance
1. Automation of NV opening control	• Manual control is unsuitable for high-rise buildings to prevent a fall accident. • NV opening should be controlled for each individual tenant to meet their own needs. • Automated control can reduce cooling load, keeping low velocity in the occupied zone. • NV opening can be controlled even in the time of disaster by emergency power supply.	△
2. Contrivance in NV opening design	• Cranked shape to obstruct rainwater blowing horizontally toward the high-rise building. • Providing a flap in the opening as a countermeasure against the blast which cannot be detected by anemometers.	○
3.Contrivance in NV inlet opening	• Adapting the horizontal inflow in the vicinity of the ceiling utilizing Coanda effect to deliver fresh air to the interior zone with high heat load. • Stable ventilation induced by buoyancy using the corner and centre voids.	○
4.Contrivance in NV outlet opening	• Surrounded by high-rise buildings in the same order, buoyancy-induced natural ventilation by voids was adopted to achieve stable and reliable exhaust advancement. • Reduce unevenness in NV rate among floors and tenants by area adjustment and distributed arrangement of the voids.	△

Table. 13 Key Lessons Learned **Operation / Post Occupancy**

Item	Lesson	Importance
1. Selection by occupants themselves	• Facilitate to choose operation mode by providing a simple two-option choice for NV.	○
2. Operation methods	• Application via web as well as ON/OFF of the air-conditioning and lighting. • Schedule setting is also enabled.	○
3. Incentive for occupants (tenants)	• According to monitored operating time of NV, air-conditioning charge is discounted.	○
4. Visualization of NV propriety (Natural ventilation forecast)	• Notification of outdoor temperature in real time and indication of the predicted temperature time series graph on the web.	△
5. Visualization of energy consumption	• Visualize the energy consumed for air-conditioning and lighting for each tenant. • By enabling comparison with other tenants, further energy saving is intended.	△

9. References & Key Contacts

9.1 References

Title	Authors	Source
Natural Ventilation Performance of High Rise Office Building with Corner-Voids		
(Part 1) Outline of Natural Ventilation Design and Flow Rate at Natural Ventilation Openings	OHMORI (Osaka University) et al.	SHASE（Kinki）2013
(Part 2) Natural Ventilation Performance Distribution by means of Tracer Gas Method	TANAKA (Osaka University) et al.	SHASE（Kinki）2013
(Part3)Outline of Ventilation Design and Ventilation Rate by Differential Pressure Measurement	TANABE (Nikken Sekkei Ltd) et al.	SHASE 2013
(Part 4) Evaluation of Natural Ventilation Performance using Flow Network Calculation	OHMORI (Osaka University) et al.	SHASE 2013
(Part 5) Characteristics of Fresh Air Distribution and Comparison of Air Flow Rate	TANAKA (Osaka University) et al.	SHASE 2013
(Part 6) Natural Ventilation Characteristics using Flow Network Calculation	OHMORI (Osaka University) et al.	SHASE（Kinki）2014
(Part 7) Indoor Environment and Occupancy Evaluation in Autumn	TAMAKI (Osaka University) et al.	SHASE（Kinki）2014
(Part 8) Sensibility Analysis of Outdoor Condition using Flow Network Calculation	OHMORI (Osaka University) et al.	SHASE 2014
(Part 9) Indoor Thermal and Air Environment Based on Measurement and Occupancy	TAMAKI (Osaka University) et al.	SHASE 2014
(Part 10) Measurement of Local Mean Age of Air Distribution in Partitioned Office Room	TAMAKI (Osaka University) et al.	SHASE（Kinki）2015
(Part 11) Indoor Environment and Occupancy Evaluation in Partitioned Office Room in Autumn	TAMAKI (Osaka University) et al.	SHASE 2015
(Part12) Annual Data of Natural Ventilation Rate by Measured Pressure Difference	TANABE (Nikken Sekkei Ltd) et al.	SHASE 2016
Natural Ventilation by Wind and Buoyancy Force of High Rise Office Building		
(Part1) Natural Ventilation Design and Flow Rate Distribution at Natural Ventilation Openings	OHMORI (Osaka University) et al.	AIJ（Kinki）2013
(Part 2) Distribution Properties of Local Mean Age of Air by means of Tracer Gas Method	TANAKA (Osaka University) et al.	AIJ（Kinki）2013
(Part3)Outline of Natural Ventilation Design	TANABE (Nikken Sekkei Ltd) et al.	AIJ 2013
(Part4) Flow Rate at Natural Ventilation Openings	OHMORI (Osaka University) et al.	AIJ 2013
(Part5) Characteristics of Fresh Air Distribution inside Large Office Room	TANAKA (Osaka University) et al.	AIJ 2013
(Part6)Indoor Environment Measurement and Occupancy Evaluation in Autumn	TAMAKI (Osaka University) et al.	AIJ（Kinki）2014
(Part7)Sensibility Analysis of Outdoor Condition using Flow Network Calculation	OHMORI (Osaka University) et al.	AIJ 2014
(Part8)Effects of Natural Ventilation on Distribution of Indoor Physical Environment and Occupancy Evaluation	TAMAKI (Osaka University) et al.	AIJ 2014
(Part9)Fresh Air Distribution inside Partitioned Office Room	TAMAKI (Osaka University) et al.	AIJ（Kinki）2015
(Part10)Field Survey on CO2 Concentration and Room Temperature in Partitioned Office in Autumn	TAMAKI (Osaka University) et al.	AIJ 2015
(Part11) Annual Data of Natural Ventilation Rate by Measured Pressure Differential	TANABE (Nikken Sekkei Ltd) et al.	AIJ 2016
Increasing of Natural Ventilation Performance of Partitioned Room in High-Rise Office Building by using Several Vertical Ventilation Shafts	TAMAKI (Osaka University) et al.	2015Ventilation

9.1 Key Contacts

Company	Role	Contact		
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13_PT_CML Kinder.
Key Features & Climate

1.1 Introduction

The CML kindergarten is a small two-story building with a total area of 680 m^2 distributed in two floors with 3m floor to ceiling height (figure 1). Construction finished in 2013. This school is located in the mild Subtropical-Mediterranean climate of Lisbon, Portugal, characterized by mild winters (minimum temperature ≈ 4ºC) and dry summers with high levels of solar radiation (maximum temperature ≈ 37ºC). In spring and summer there are many days with large thermal amplitude (up to 18ºC), that can potentially make a night cooling approach very effective. In a typical school building in Lisbon it is expected that the main comfort problems occur when high direct radiation levels and the maximum outdoor temperatures are combined with high internal gains, easily leading to cooling loads of up to 100W/m^2.
Driven by the need to lower maintenance costs, the building is naturally ventilated and does not have a mechanical cooling or ventilation.

Fig.1 CML Kindergarten, Portugal

Table.1 Key Information about building

Location	Lisbon, Portugal
Building Type	Kindergarten
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Urban
Ventilative Cooling Strategy	SS and DV
Year of Completion	2013
Floor Area (m^2)	680
Shape Coefficient (%)	32
Openable Area to Floor Area Ratio (%)	8
Window to Wall Ratio (%)	18
Sensible Internal Load (W/m^2)	53
Climate Zone (KG)	Csa
No. of Days with T_e max > 25	120
Cooling Season Humidity	Low
Heating Degree days (Kd)	215

1.2 Local Climate

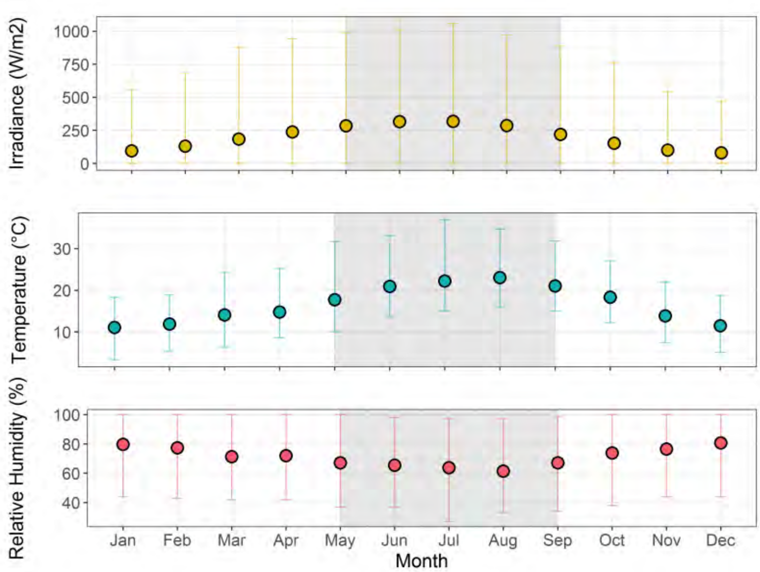

Fig.2 Mean, maximum and minimum external conditions in Lisbon using TMY3 from Meteonorm 7 (cooling season shown shaded)

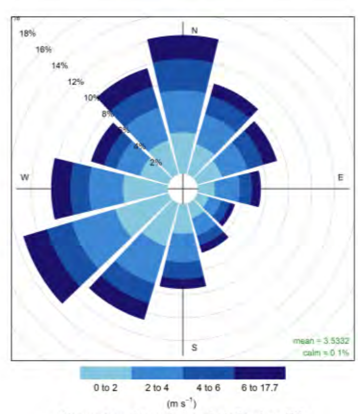

Fig.3 Wind rose for Lisbon

2. Building Information

2.1 Description

Due the imposed need of low maintenance costs, were installed user-controlled hybrid lighting, ventilation and air conditioning systems. With the goal of maximizing thermal inertia, the walls are made of exposed concrete and have external insulation. Summer solar heat gains are limited by horizontal overhangs and low-emissivity double glazed windows with external shading (λ=0.9 W/m.K; τ=0.75). Figure 4 shows exterior and interior views of the kindergarten classrooms. Heating is provided by passive convectors, feed by a heat pump. NV air is introduced into the space through low level grilles or by windows opening on the façade and is exhausted in the center or back of the room, through one or two chimneys (depending on classroom dimensions).

Fig 4. Inside and exterior views of the CML Kindergarten. Architectural drawings.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m²/p	2.4
Hours of occupancy	h/week	70
Sensible Internal Load	(W/m²)	53
Window U-value	W/m²K	3.5
Window g-value	(-)	0.75
Wall U-value	W/m²K	0.59
Roof U-value	W/m²K	0.38
Floor U-value	W/m²K	0.41
Q-value (from Japan)	(W/ m²)/K	-
Thermal Mass (ISO 13790)	-	Heavy
Window to Wall Ratio	%	18
Air-tightness (@50 Pa)	1/h	1
Shape Coefficient (1/m)	%	32

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	•
Energy costs	•
Solar Loads	●
Internal Loads	●
External Noise	•
Internal Noise Propagation	•
Air Pollution	•
Rain Ingress	●
Insect prevention	●
Burglary prevention	●
Privacy	●
Air Leakage	•

3. Energy Systems

CMK Kindergarten is a grid connected building.

Fig. 5 INSTALLED ST PANELS ON CML KINDERGARTEN ROOF.

3.1 Heating System

For the thermal conditioning of the space, the buildings Portuguese national code only requires the installation of an active system for the heating period. For this purpose, a hydraulic radiator was installed in each classroom (after the inflow grilles). This radiator is fed by a heat pump, with a maximum heating power output of 38.6kW and a COP of 3.5.

3.2 Hot Water Supply (ST)

CMK Kindergarten uses solar thermal (ST) energy to heat domestic hot water (DHW) that fed the hydraulic radiators (see figure 6). The heat pump is used every time that ST system cannot supply the required amount of energy. Solar thermal system is composed by 6 solar panels (see figure 5) and a 500L water deposit.

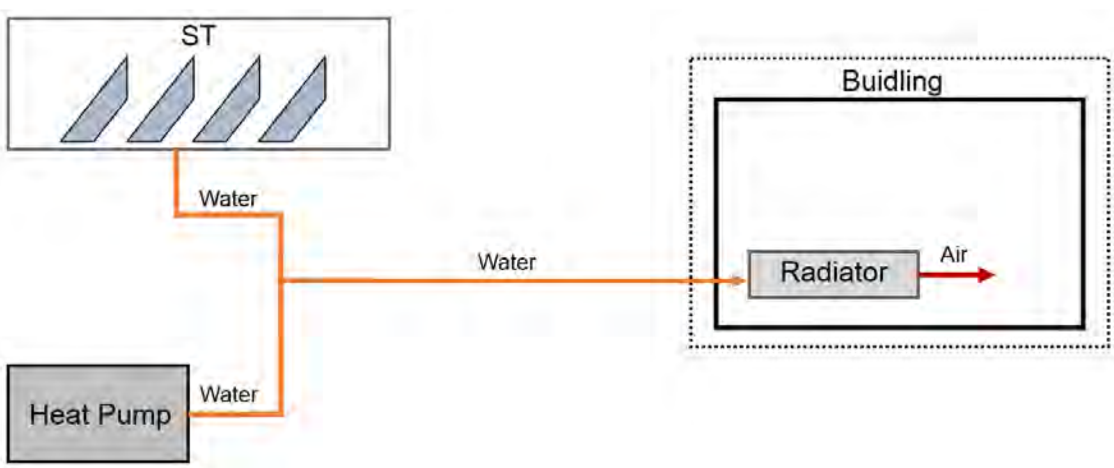

Fig.6 SCHEMATIC DESCRIPTION OF CML KINDERGARTEN HEATING SYSTEM

4. Ventilative Cooling

4.1 Principles

In CML Kindergarten two different natural ventilation strategies could be employed: displacement ventilation (DV) and single sided (SS) ventilation. In DV systems air is introduced near the room floor with low velocity. Buoyancy forces induced by temperature differences between inflow and room air heated by internal gains promote airflow across the floor towards the heat sources where the ventilation air expands and moves upward. Ideally, the air movement induced by buoyancy is capable of transporting heat and pollutants away from the occupied zone, promoting stratification, creating a warmed mixed layer in the upper part of the room. In order for the buoyancy forces to be effective, DV systems require a height difference between inflow and outflow that is difficult to achieve without chimneys.

SS is characterized by mainly use the wind pressure on building shape to induce air currents through the openings on the façade. This strategy could use one or more windows in the same façade and is also affected by local buoyancy effects that can promote bi-directional flows. SS should be used during the cooling period in order to enable larger flow rates to remove the higher heat gains.

Fig.7 INTERNAL AND EXTERIOR VIEWS OF KINDERGARTEN

4.2 Components

The ventilation solution implemented in this kindergarten consists in an high-level openable window plus low-level grilles installed on the façade of each classroom that control the inflow air. During the colder months an hydraulic radiator that was installed in front of the grilles (figure 7 and 8) could be used to ensure users thermal comfort. The air will be exhausted in the back of the room, through one or two thermal chimneys (depending of classroom size, figure 9) For optimal performance of the ventilative cooling systems designed two operation modes were considered: winter and summer.

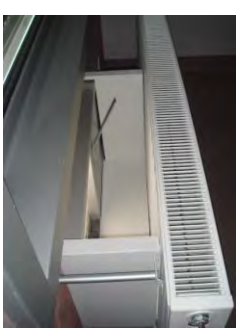

Fig. 8 INFLOW AIR GRILLE PLUS RADIATOR

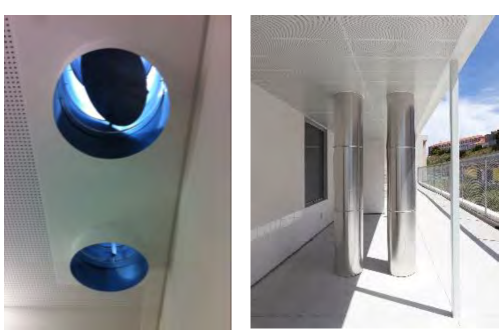

Fig. 9 CHIMNEY

Table. 4 COMPONENTS CAPACITY DIMENSIONING

Parameter	Value
Type (Inlet)	Grille
Free opening area (m^2)	0.26
Inlet Discharge Coefficient (Cd)	0.32
Type (Outlet)	Chimney
Free opening area (m^2)	0.08
Outlet Discharge Coefficient (Cd)	0.50
Porosity (A_w/A_f)	8%
Q (@ Vel = / ΔP =	TBC m^3/s

5. Control Strategy

5.1 Control Strategy Overview

Children spend the majority of their weekdays in classrooms that often have low indoor air quality and limited financial resources for the initial and running costs of mechanical ventilation systems. For these reasons, the implemented natural ventilation strategies are manually operated and there usage relies on the occupant perception of the internal environment.

For optimal performance of the ventilative cooling systems designed two operation modes were considered: winter and summer (figure 10). The main thermal comfort problems occur in the summer, when it is necessary to promote the interior air renewal (to maintain acceptable CO_2 concentration) but the outside air is warmer. Ideally, in these moments all the openings should be closed to achieve comfortable interior air temperature but open to do not exceed 1625ppm (CO_2 concentration). In these cases, the users will determine what comfort parameter is more relevant to his comfort and to define if the openings should be maintained closed or be opened.

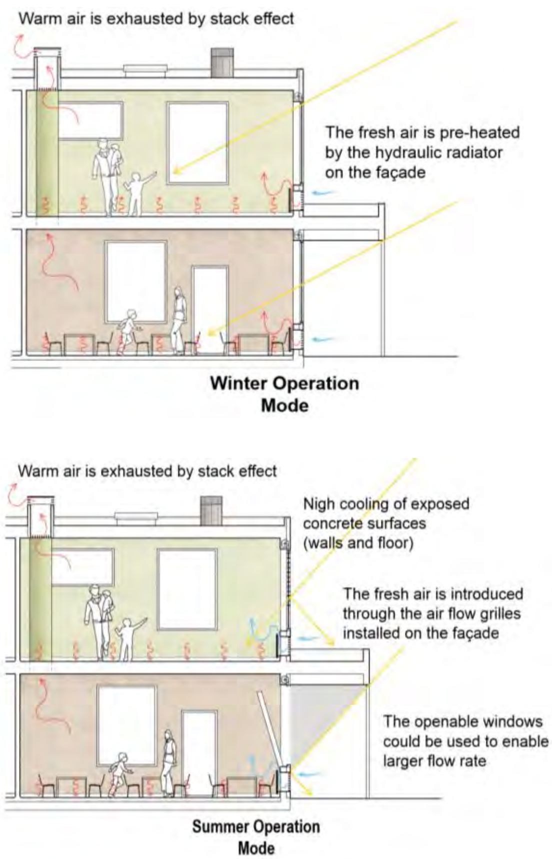

Fig. 10 WINTER AND SUMMER OPERATION MODES

5.2 Control Strategy Description

During heating period (winter mode), due to the buildings regulation impositions the airflow grilles should be opened to provide the required minimum airflow (fresh air) in order not to exceed CO_2 concentration limit (average below 1625ppm over an 8h period). In this mode, the air that enters though the grilles and was pre-heated directly in front of the passive heating convector that maintain the interior air temperature always above 19ºC.

In summer mode (during the cooling period), all the openings on the façade (low level grilles and openable windows) will be available to be opened, in order to enable larger flow rates to remove the higher heat gains.

Table 5 lists the controlling strategies followed by the users.

Table. 5 CONTROL STRATEGY

Season		Grille 0%= closed, 100% = open	Chimney 0º= closed, 90º = open	Window 0%= closed, 100% = open
Winter/Autumn	Day Night	30% 0%	30º 0º	30% 0%
Spring	Day Night	50% 50%	45º 45º	50% 0%
Summer	Day Night	100% 100%	90º 90º	100% 100%

6. Design Simulation

6.1 Summary

The design simulations were performed in EnergyPlus, version 8.3.0. The thermal zoning strategy used in simulation models impacts the results and must be carefully defined. In the present case, two thermal zones were considered (figure 11): room and thermal chimney. The two thermal zones are connected by a virtual horizontal opening.

NV flow was simulated using the airflow network model that has the capability to simulate multizone buoyancy and/or wind driven airflow. This model allows for manual introduction of wind driven pressure coefficients or automatic generation. In the present case the buildings are located in an urban environment influenced by several surrounding buildings, resulting in low wind driven surface pressures. Further, during the measurement period the average wind velocity was ≤0.5m/s. This effect combined with the opening configurations, designed to reduce wind driven shear ventilation effects, makes the impact of wind on NV airflow negligible. In this context, the simulation flows are driven exclusively by buoyancy. Table 6 highlights what tools were utilised at each stage of the project while Table 7 summarises the target design performance criteria.

Table. 6 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	EnergyPlus	Define Environmental Criteria
Concept Design	EnergyPlus	Initial Overheating Check
Detailed Design	EnergyPlus	Thermal Analysis, Loads & ACR
Construction Design	EnergyPlus	Energy Performance

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	30
T_z , Summer Operative Temp	26ºC
Overheating criteria	Adaptive comfort model (80% acceptability limit) for 99% hr_{occ}
Min IAQ air supply rate	7l/s/occupant
Cooling air supply rate	-
Noise Level Rating	-

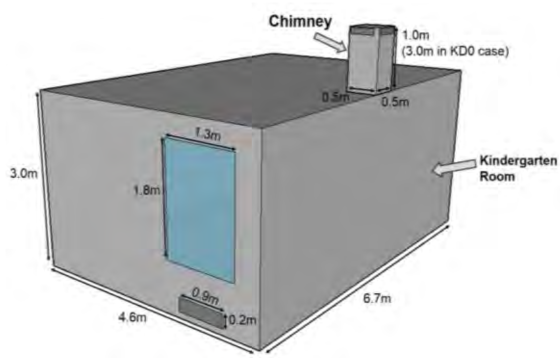

Fig. 11 CML KINDERGARTEN CLASSROOM MODEL

6.2 Simulation of overheating risk

Figure 12 show the predicted yearly operative temperature evaluated according to ASHRAE 55-2010 criteria.

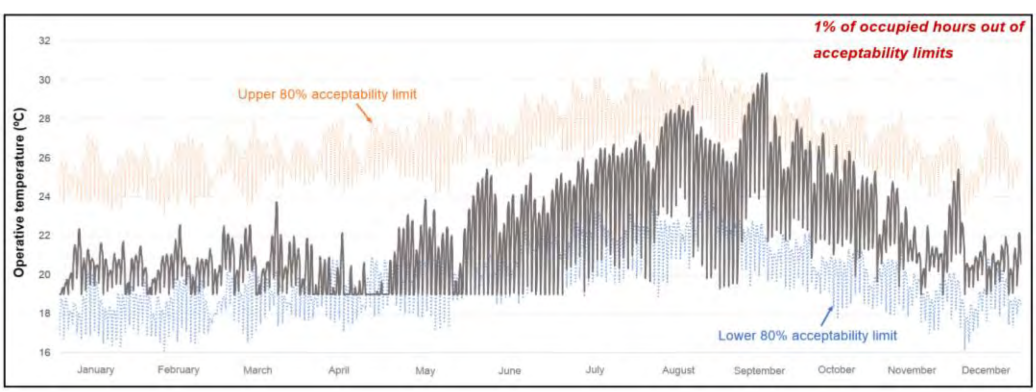

Fig.12 CML KINDERGARTEN OPERATIVE TEMPERATURE ADAPTIVE COMFORT ANALYSIS (ASHRAE 55-2010).

7. Performance Evaluation

7.1 Ventilation rates

The natural airflow rates were measured in controlled test conditions with constant sensible gains, provided by heated cylinders (sensible heat gains, split in 65% convective and 35% radiative) with a constant CO_2 release (3.72x10-5 kg/s per simulator, in all cases). The measurements were performed in two classroom with different chimney height and heat gains densities (Mateus and Graça, 2016). The bulk airflow rate was determined when steady state conditions are reached solving the mass balance described by the Equation 1 (Persily, 1997), using CO_2 released by near the cylinders as a tracer gas (Wallider et al., 1997), according to:

$$F\ (m^3/s) = \frac{CO2_{simulators}\ (mg/s)}{[CO_{2outlet}]-[CO_{2inlet}]\ \ (mg/m^3)} \qquad (1)$$

Figure 13 and table 8 present the comparison between the simulated and measured bulk airflow rate. Overall, there is a good agreement (r^2=0.77), negligible bias (10l/s) and the average error of 16%. The comparison between kindergarten cases KD1_1_5P and KD0_1_5P (3.5m and 6.5m stack height, respectively) shows, as expected, an increase of 170% in the airflow rate of higher chimney case.

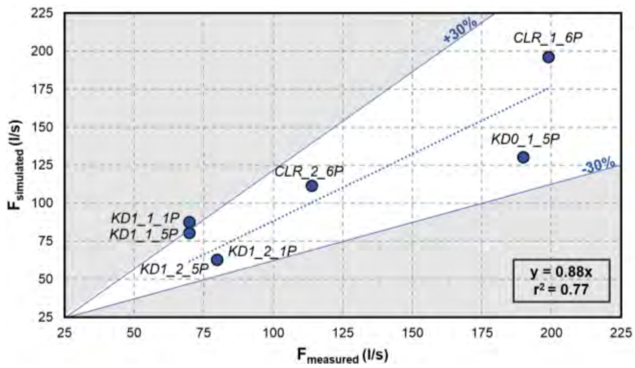

Fig. 13 BULK AIRFLOW RATE RESULTS: MEASURED VS SIMULATED.

Table 9 PERCENTAGE HOURS EXCEEDANCE

Parameter	Typical year (TMY)
Total Hours > 25°C	12%
Occ Hours > 25°C	16%
Total Hours > 26°C	7%
Occ Hours > 26°C	10%

Table 8 BULK AIRFLOW RATE RESULTS: MEASURED VS SIMULATED

Case	$F_{measured}$ (l/s)	$F_{simulated}$ (l/s)	Avg. Bias (l/s)	Error (%)
CA0_1_5P	190.0	130.0	-60.00	31.6
CA1_1_5P	70.0	80.0	10.00	14.3
CA1_2_5P	80.0	63.0	-17.00	21.3
CA1_1_1P	70.0	87.0	17.00	24.3
CA1_2_1P	80.0	63.0	-17.00	21.3
Avg. Error			-13.4	22.56

7.2 Thermal comfort and IAQ level

Figure 14 presents the simulations results for a whole year, using the TMY weather file for Lisbon (EnergyPlus Weather), the rooms IAQ level promoted by the natural ventilation systems should be in agreement with buildings Portuguese code (RECS, 2013). Table 9 provides summary data on hours of exceedance for each per year.

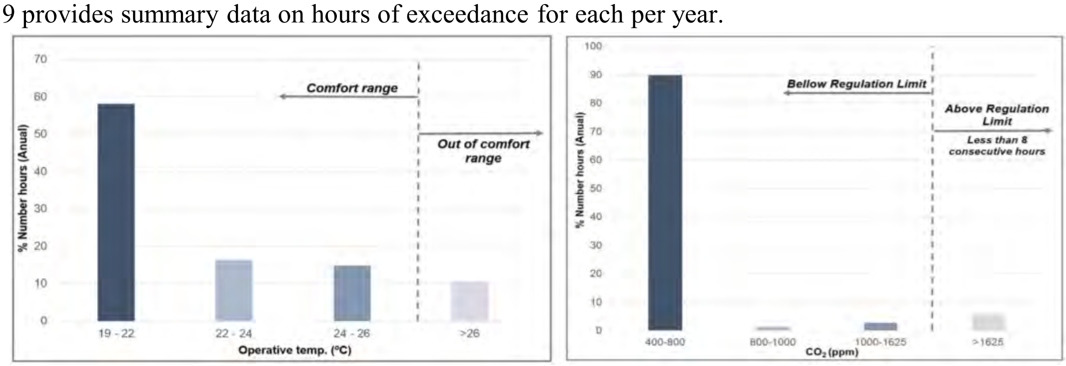

Fig. 14 ANNUAL STATISTICAL ANALYSIS: INDOOR AIR TEMPERATURE AND CO_2 CONCENTRATION

7. Performance Evaluation

7.3 Short-term measurements – internal temperatures

The experimental setup of the kindergarten short-term measurement cases allows for the evaluation of the impact of ventilation opening area (A*), number of plumes and chimney height on neutral height position and room air temperature when DV strategy is used. Figure 15 we can see the impact of a reduction of 50% in the inflow area (15% reduction in A*): as the inflow rate decreases the indoor air temperature rises. Figure 16 displays the effect on natural DV system performance of increasing the number of plumes (1 to 5): higher flow rate and, for the same outdoor temperature, lower indoor air temperature.

Figure 17 presents the impact of room stack height on indoor air temperature profile. The two lines shown in the figure were measured simultaneously in the 3m and 6m stack rooms using similar internal gains). These results confirm that, as expected, doubling the stack height increases the airflow rate and lowers the indoor air temperature (≈1ºC at 1m). For these cases, the temperature increased between indoor and outdoor is 5-6ºC. This large value is partially due to the high internal gains used in the tests (66W/m²).

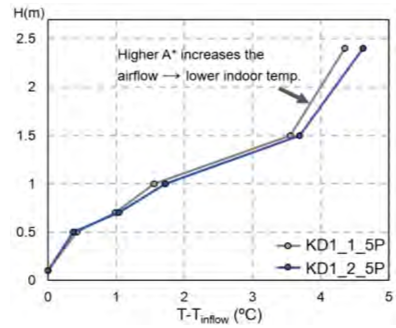

Fig. 15 SHORT-TERM MEASUREMENTS : A* IMPACT ON INDOOR AIR TEMPERATURE.

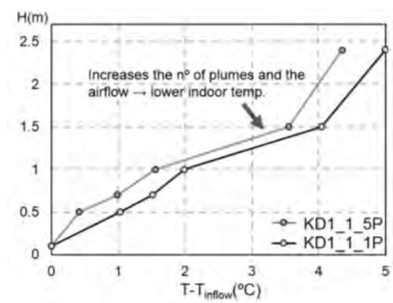

Fig. 16 SHORT-TERM MEASUREMENTS : NUMBER OF PLUMES IMPACT ON INDOOR AIR TEMPERATURE.

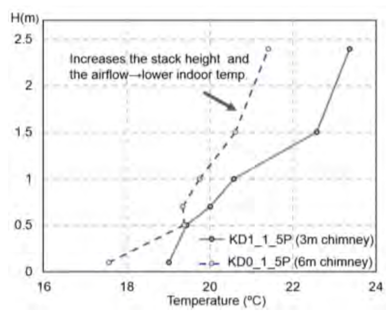

Fig. 17 SHORT-TERM MEASUREMENTS : IMPACT OF CHIMNEY HEIGHT ON INDOOR AIR TEMPERATURE.

7.4 Long-term measurements – internal temperatures

Internal air temperature have been measured and recorded in the main spaces since mid 2016. The typical building occupancy is on average 14 people in each classroom during occupied hours (08:00 – 19:00). Figure 18 and 19 present indoor air temperature and CO_2 concentration of two periods:18 to 30 April and 16 May to 12 June. Table 10 provides summary data on hours of exceedance per year.

Table. 10 TABULATED RESULTS

Parameter	Typical year
Total Hours > 25°C	12%
Occ Hours > 25°C	16%
Total Hours > 26°C	7%
Occ Hours > 26°C	10%

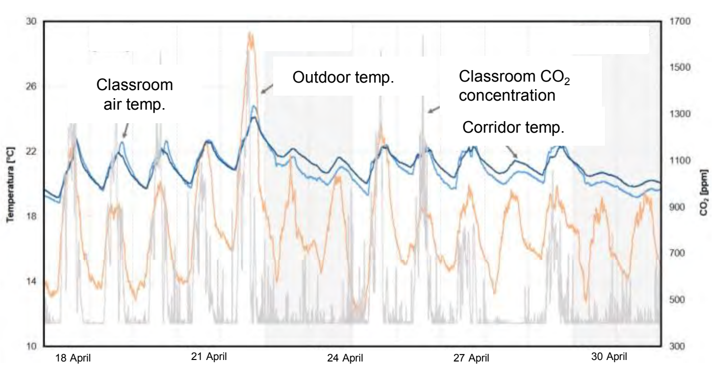

Fig. 18 TYPICAL HEATING AND COOLING SEASON OCCUPANCY PROFILES

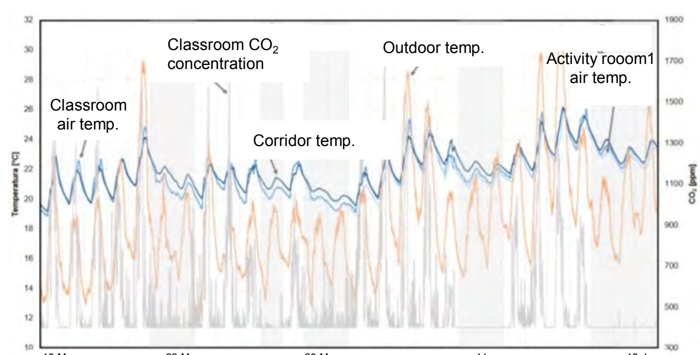

Fig. 19 TYPICAL HEATING AND COOLING SEASON OCCUPANCY PROFILES

7. Performance Evaluation

7.5 Performance Simulation

This section presents the evaluation of the thermal simulation precision for the short-term experimental cases (considering only DV ventilative cooling strategy). The simulations are evaluated by comparing EnergyPlus DV model temperature nodes (Mateus and Graça, 2015). The differences between the predicted and measured airflow rates were quantified using the following error indicators: average difference (ºC), average bias (ºC) and average error (%). Figure 20 show the results of the temperature obtained in the three-node model simulation.

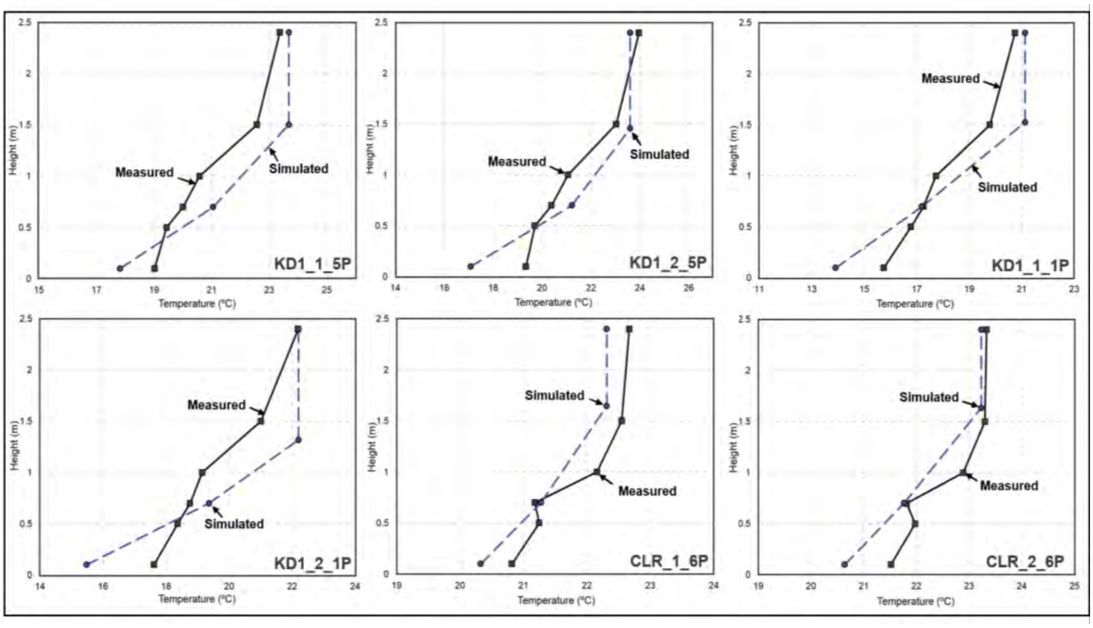

Fig.20 ENERGYPLUS THREE-NODE DV MODEL TEMPERATURE RESULTS COMPARISON.

Table 8 shows the values of the average error indicators for the node temperatures in the temperature profiles of the seven experimental cases. The average simulation error is 4%, corresponding to an average difference of 0.7ºC. In the node with the largest average error, T_{af} (8%), there is a systematic under prediction. The overall agreement in the other two air nodes, T_{MX} and $T_{OC,}$ is very good: the maximum error achieved is less than 6%. As expected, the agreement in T_{MX} node is higher due to the imposed mass/energy balance on the model structure.

Table. 11 COMPARISON BETWEEN MEASURED AND SIMULATED NODE TEMPERATURES: T_{AF}, T_{OC} AND T_{MX}.

Case\Node	Avg. Dif.(ºC)			Avg. Bias (ºC)			Avg. Error (%)		
	T_{AF}	T_{OC}	T_{MX}	T_{AF}	T_{OC}	T_{MX}	T_{AF}	T_{OC}	T_{MX}
KD0_1_5P	1.4	1.0	0.2	-1.4	-1.0	-1.0	7.7	5.1	0.8
KD1_1_5P	1.2	1.0	0.3	-1.2	1.0	0.0	6.3	5.2	1.3
KD1_2_5P	2.3	0.8	0.4	-2.3	0.8	0.0	11.6	4.1	1.5
KD1_1_1P	1.8	0.1	0.4	-1.8	-0.1	0.0	11.7	0.3	1.9
KD1_2_1P	2.1	0.6	0.0	-2.1	0.6	0.0	12.1	3.2	0.1
Average indicators	1.7	0.7	0.2	-1.7	-0.2	-0.1	9.8	3.5	1.1

8. Lessons Learned

8.1 Summary

This section contains a summary of the key lessons learned during the delivery of the project, both during design phases, construction phases and any feedback from commissioning and post occupancy evaluations.

8.2 Detailed list of lessons learned

Table. 12 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1 Stack driven NV in spring and winter	Stack driven NV is very effective and self regulating and can meet the airflow rate goals in spring and winter	High
2 Manual control	If possible the system should have easily accessible manual control	High
3		
4		
5		

Table. 13 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1 User training	User training is essential and may need to be periodic (every 3-4years). In this school the current users were convinced that the chimneys were poorly designed skylights.	High
2		
3		
4		
5		

9. References & Key Contacts

9.1 References

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9.1 Key Contacts

Table. 14 KEY PROJECT CONTACTS

Company	Role	Contact
Lisbon Municipality	Client & Project Research Team	http://www.cm-lisboa.pt/en
Appleton Domingos	Project Architect	http://www.appletondomingos.pt/
Natural Works	Project Engineers	http://www.natural-works.com/
HCI	Main Construction Contractor	http://www.hci.pt/en/

1.1 Introduction

The case-study is a seminar room at a university campus in West England. The examined ventilative cooling system (CoolPhase by Monodraught Ltd) has been installed in many rooms (typical classrooms and offices) of the building (Figure 1) but a seminar room was chosen for this case-study because of its use (computer laboratory) with higher internal heat gains. The system installed uses the principle of ventilative cooling with phase change material (PCM) thermal batteries to cool the space based on monitored air temperature while Indoor Air Quality (IAQ) is controlled by monitoring metabolic CO_2.

Fig.1 External View of the Building

1.2 Local Climate

Climate is temperate maritime with 2684 Heating Degree Days and 196 Cooling Degree Days; 20 year average, base 15.5°C, SW England [1].

Table.1 Key Information about building

Location	Bristol, UK
Building Type	School
Retrofit (Y/N)	Y
Surroundings (Urban / Rural)	Rural
Ventilative Cooling Strategy	Mechanical
Year of Completion	2013
Floor Area (m^2)	117
Shape Coefficient (%)	50
Openable Area to Floor Area Ratio (%)	4
Window to Ext Wall Ratio (%)	50
Sensible Internal Load (W/m^2)	54
Climate Zone (KG) (words?)	(Cfb)
No. of Days with T_e max > 25	17
Cooling Season Humidity	Medium
Heating Degree days (Kd)	2684

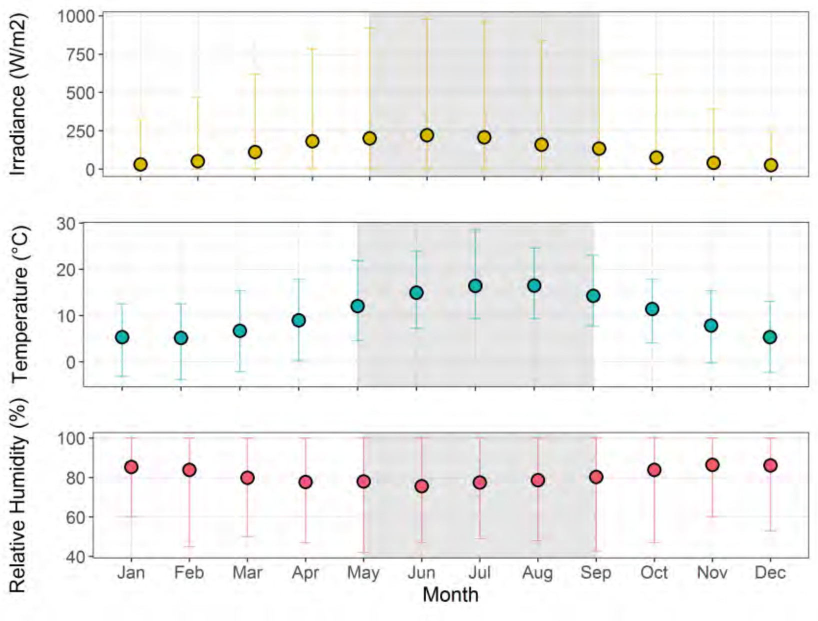


Fig.2 Mean, maximum and minimum external conditions in Bristol using TMY3 from Meteonorm 7 cooling season is shaded in grey

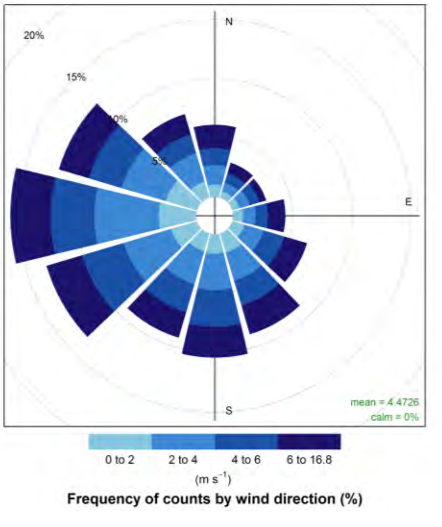
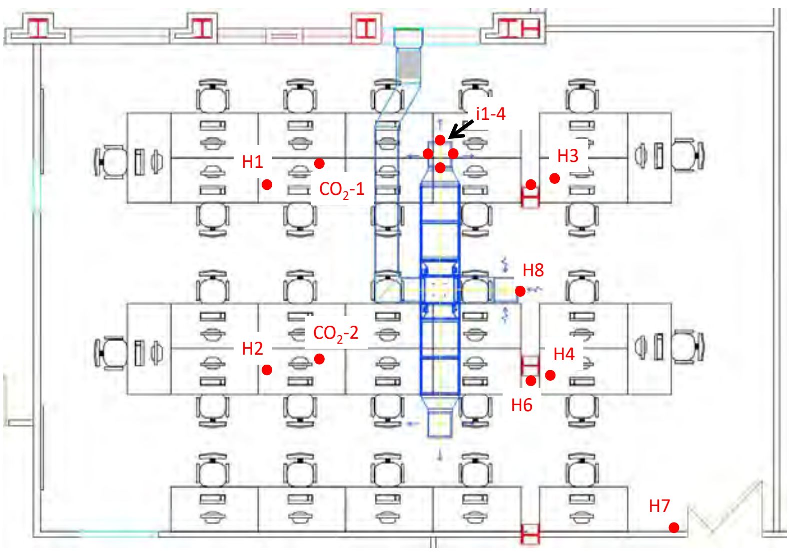


Fig.3 Wind rose for Bristol (TMY3)

2. Building Information

2.1 Description

The room was renovated into a seminar room by joining three pre-existing rooms. The existence of a plenum favoured the installation of the suspended ceiling CoolPhase model instead of any of the other two models (Fascia and Exposed void). The refurbished seminar room floor plan can be seen in Figure 4 where the position of space monitoring sensors (for the purpose of this case study) are shown as well as an internal photo of the room. Table 2 presents the Building properties and design influences.



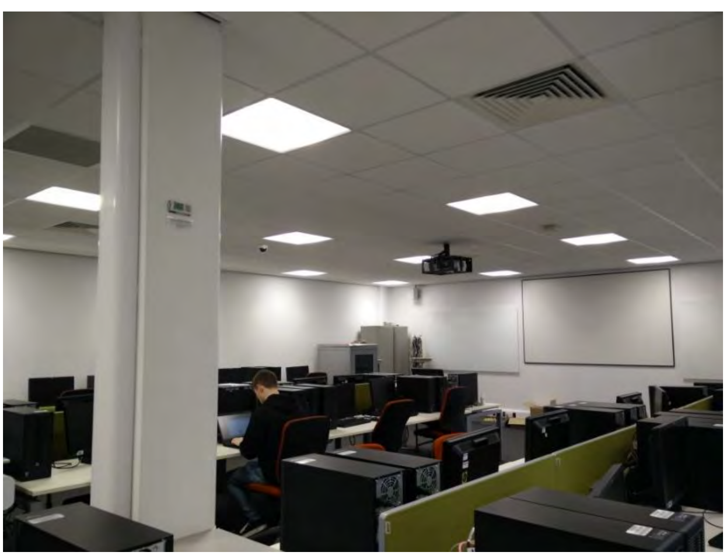


Fig 4. Top image presents the floor plan of the retrofitted room with the position of the CoolPhase unit and location of monitoring equipment (H=HOBO, i=i-button). Bottom figure illustrates the room with inlet and exhaust diffusers visible.

Table.2 Building Properties and Design influences

Property	Unit	Value
Occupant density	m^2/p	4
Hours of occupancy	h/week	60
Sensible Internal Load	(W/m^2)	54
Window U-value	W/m^2K	1.82
Window g-value	(-)	0.43
Wall U-value	W/m^2K	0.56
Roof U-value	W/m^2K	NA
Floor U-value	W/m^2K	2.11
Q-value (from Japan)	$(W/m^2)/K$	
Thermal Mass (ISO 13790)	-	Medium
Window to Wall Ratio	%	50
Air-tightness (@50 Pa)	1/h	<10 m^3/hm^2
Shape Coefficient (1/m)	%	50%

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	●
Maintenance Costs	●
Energy costs	●
Solar Loads	•
Internal Loads	●
External Noise	•
Internal Noise Propagation	●
Air Pollution	•
Rain Ingress	●
Insect prevention	●
Burglary prevention	●
Privacy	•
Air Leakage	•

3. Energy Systems

The seminar room is part of a larger building. It is heated by perimeter radiators positioned at the external wall and power is provided for lighting and equipment from the grid. Ventilation and cooling are provided by the CoolPhase system.

4. Ventilative Cooling

4.1 Principles

The CoolPhase system uses the concept of a thermal battery consisting of Phase Change Material (PCM) plates within the ventilation path to capture and store heat. Therefore, the thermal batteries use the latent heat property of materials to store energy, which is charged and discharged by passing air through a heat exchanger (see Figure 6). Air is drawn from outside or the room using a variable speed fan. During operational hours and depending on internal air quality (monitored through CO_2 sensors) the air is mixed with recirculated air from the room to conserve energy. The air is then directed through the PCM thermal battery to be cooled if necessary (determined by air temperature sensors and control rules) or by-passes it if cooling is not needed. Outside operational hours, ambient air is used to recharge the PCM thermal battery the duration of which is determined by air temperature sensors and control rules according to the season.

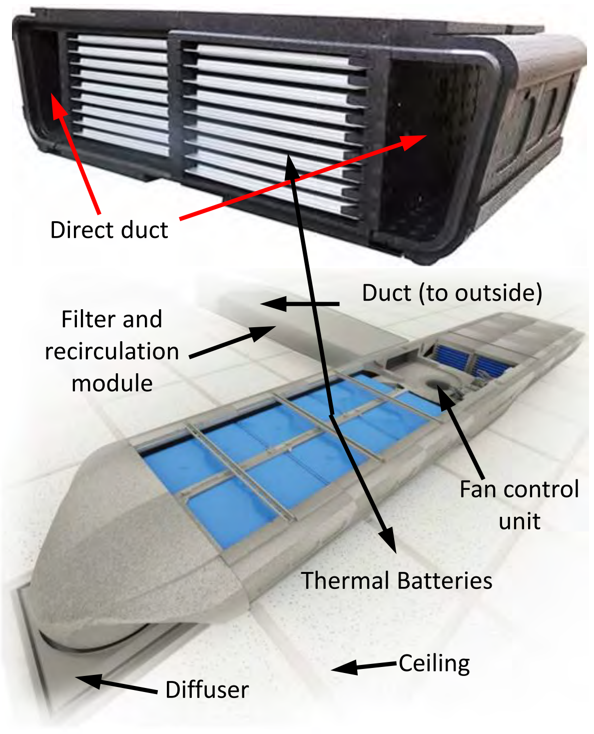
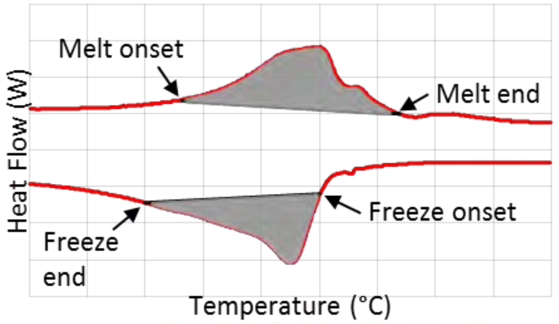


Fig. 5 COOLPHASE UNIT COMPONENT [4]

4.2 Components

The equipment consists in a G4 filter, recirculation damper, fan, thermal batteries and diffusers. An electronic system controls the damper and directs the airflow through thermal batteries or bypass it through a EPP Expanded Polypropylene duct. The thermal battery size varies according to capacity and model; 3995mm to 5805 mm width, 966mm depth and 400mm height. The fan provides 260 L/s maximum during cooling mode and 300 L/s during charging mode.



Sensor points analysed in this work
T1= Outside Air
T2= Recirculation Air
T5=Air before battery
T7= Air after battery

TUI, CO2, HUI =
air temperature, CO2 concentration, relative humidity, inside the room

Additional monitoring in the room for this case study was carried out as shown in Fig 4.

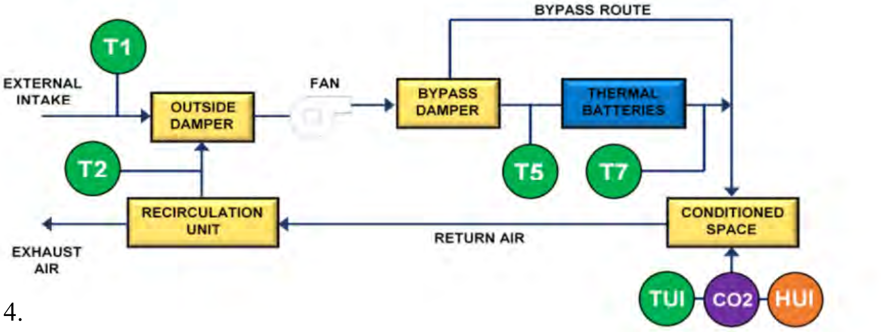


Fig. 6 COOL-PHASE PRINCIPLE

5. Control Strategy

5.1 Control Strategy Overview

The control system has default set-points according to country guidelines [5] but the user is able to adapt it according to needs. Table 4 presents the set-points where air temperature varies according to the season and airflow rate according to metabolic CO_2 and air temperature. Figure 7 shows the flowchart of the control system.

Table. 4 CONTROL STRATEGY PARAMETERS

Season	Autumn	Winter	Spring	Summer
Start day	01-Oct	01-Dec	01-Mar	01-May
Temperature	23	24	23	22
Desired CO_2 (ppm)	900			
High CO_2 (ppm)	1200			
Charging mode	1:00 to 6:59			
Cooling mode	8:00 to 20:59			
Boost Charge mode	00:00 to 00:59			

Approx. Flow Rate (l/s)	Temperature (°C)	CO_2 Level (ppm)	Notes
300			
240	26°C	1800	Maximum under normal conditions
210	25°C	1600	
175	24°C	1300	
140	23°C	1000	
100	22°C	900	Default Minimum level
0	Off	Off	

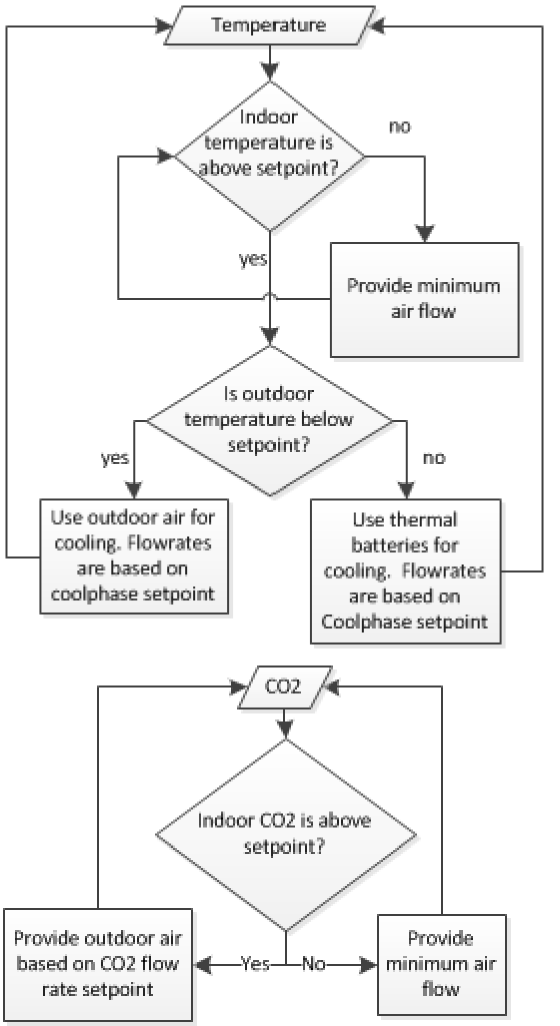


Fig. 7 COOL-PHASE CONTROL FLOWCHART

5.2 Control Strategy Description

CoolPhase is a demand control system based on air temperature and CO_2 levels inside the room. To adjust the air temperature, the airflow can cross the thermal batteries with air recirculated from the room or from outside. If the room exceeds CO_2 concentration limit, outside damper open and fresh air is introduced to reduce CO_2 concentration until the set point is achieved. A summary of the CoolPhase control system strategy is presented of Table 5.

Table. 5 COOLING MODES

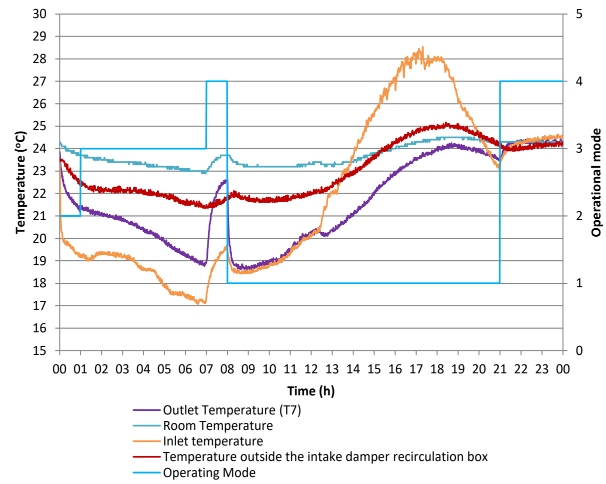
Direct outside air ventilation	Used when the outside temperature is cooler than inside, the air is inflated into the room bypassing the thermal battery until it reaches a set point temperature.
Outside ventilation and cooling	Used when the outside temperature lower than inside but is not enough to cool the space, the air cross the thermal before get inside the room.
Recirculation and cooling	When the temperature outside is higher than inside, recirculating air passes over the thermal batteries to offer cooling.
Summer Charging	During unoccupied hours, the system blows outside cold air to charge the thermal batteries and release the build-up heat. When thermal batteries are full charged, the system turn off automatically.
Heat recovery cycle	In winter times, when the room is unoccupied or warm, the air is re-circulated through the thermal batteries to charge and use it to reduce the heating system load.
CO_2 control	When CO_2 concentration on indoor environment is higher than a specific set point, outside air is inflated.
Humidity control	When the room humidity is lower or higher of a preset set point, the system will alter outside air inflation until achieve the design value zone.

For all modes during occupied hours, an outside minimum volume flow is required by regulations to ensure a minimum air changes per hour (ach).

6. Design Simulation

Monodraught Ltd uses IESVE [3] to design their system for the building under consideration as well as other in-house tools for specific applications. ISEVE has a plug-in that enables the user to design the system by changing parameters such as the system type, size and number of units required according to the heat gains. The system was sized for this case-study and some of the results are presented in the performance evaluation section. Figure 8 presents the operation according to its design.

Fig. 8 – OPERATION OF THE SYSTEM ON A TYPICAL COOLING DAY



7. Performance Evaluation

As mentioned before data from the equipment control system were available as well as purpose monitoring inside the seminar room. These are used for the performance evaluation.

Thermal Comfort

Adaptive thermal comfort approach is used for cooling season and PMV-PPD for heating season. [6], [7]. The seminar room is considered category II (normal expectation for new buildings and renovations) where free-running buildings during the cooling period (May to September) have a comfortable range of ± 3 K from thermal comfort limit (see Figure 9) and -0.5 < PMV <0.5 and PPD < 10 for heating season (October to April).

Cooling season

The upper and lower limits of adaptive thermal comfort are based on category II ($T_{min} = T - 3$ and $T_{max} = T + 3$) with T_{min} and T_{max} calculated by: $T = 0.33\ T_{rm} + 18.8$ where T_{rm} is the running mean temperature. Figure 9 shows the results during weekdays (8:00 to 21:00). Air temperature did not exceed the upper thermal limit but some overcooling occurs for some hours.

Fig. 9 – MEASURED AIR TEMPERATURE FOR 2015 AND 2016 COOLING SEASONS AND OUTDOOR TEMPERATURE

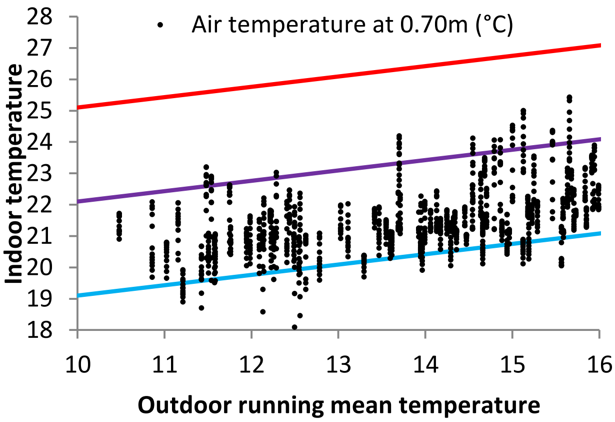
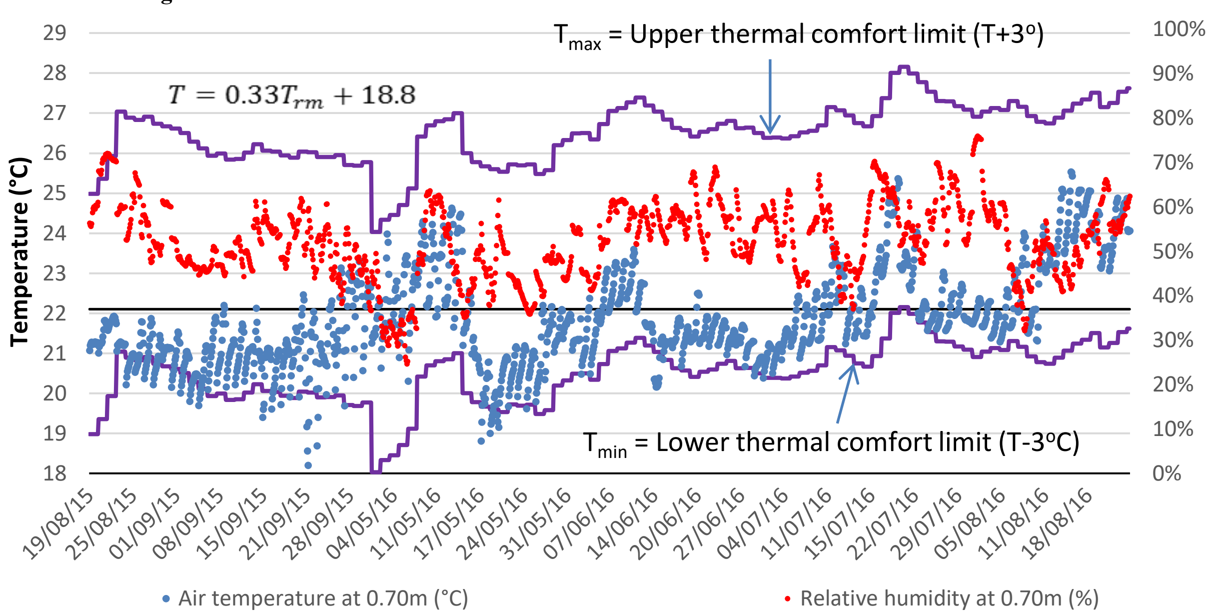


Fig. 10– MEASURED AIR TEMPERATURE AND RH IN COMPARISON TO THERMAL COMFORT LIMITS



7. Performance Evaluation

Heating season

Figure 11 presents the results for the heating season when occupants would feel uncomfortable when PMV > 0.5 or PPD <10 and outside running mean temperature (T_{rm}) is below 10 ºC. For the analysed period this represent 43 and 142 hours respectively. Furthermore, PMV shows an average temperature of 25 ºC and students might feel uncomfortable if wearing outdoor clothes. When outside running mean temperature is between 10 and 15 ºC, occupants felt uncomfortable in 51 and 142 hours for PMV < -0.5 and PPD <10, respectively and according to PPD procedure, during 13.30% of the period, occupants are dissatisfied. For PMV between 15 ºC > T_{rm} >10 ºC the lower temperature average (19 ºC) shows that students might feel uncomfortable but they are free to adapt themselves by increasing clo. Table 6 shows the minimum, average and maximum temperature with the standard deviation as well as the percentage of hours outside thermal comfort temperature for the heating period.

Table. 6 Minimum, average and maximum temperature with the standard deviation and percentage of hours outside thermal comfort temperature for the heating period.

	For T_{rm} <10 ºC		For 15 ºC > T_{rm} >10 ºC	
	PMV >0.5	PPD >10	PMV < -0.5	PPD > 10
Hours	43	142	8	22
Percentage of total (%)	2.60%	8.50%	1.80%	4.80%
Min Temperature	24.42	17.74	18.82	18.82
Avg. Temperature	24.97	20.99	18.96	20.90
Max. Temperature	25.75	25.75	19.06	24.39
Standard Deviation	0.36	2.86	0.07	2.52

Indoor air quality (CO_2 analysis)

UK guidance for schools [5] suggests that internal CO_2 levels should be below the target of 1000 ppm for any month and can not exceed 1500 ppm for more than 20 minutes. Monitored data (Figure 12) show that levels of CO_2 are below 500 ppm for approximately 60% of the occupied period and over 1500 ppm for more than 20 minutes only once in 2014 (for 29 minutes) showing good equipment performance in terms of IAQ.

Equipment performance

Figure 12 (lower) presents monitored weekday indoor air temperature frequency in percentage from 8:00 until 21:00 in 2014 and 2015. In 2014, temperatures of 24 ºC (± 0.5 K) were more frequent in winter and summer (25.8 and 28.6% respectively) while air temperature of 25 ºC (± 0.5 K) was more frequent (35.4 %) in Autumn/Spring. In 2015, the system maintained the set-point temperature more frequently during summer (35.1%) and winter (42.1%) while during Spring/Autumn, the room was slightly warmer than the set-point (37% for 24 ± 0.5 ºC). Figure 12 also shows that the system maintains the room air temperature in a range 21.5 to 26.5 ºC for most of the time in 2014 (93%) and 21.5 to25.5 for 88.7% of the time in 2015.

Fig.11 PPD and PMV during heating season for Trm <10 ºC (above) and 15 ºC > Trm >10 ºC (below)

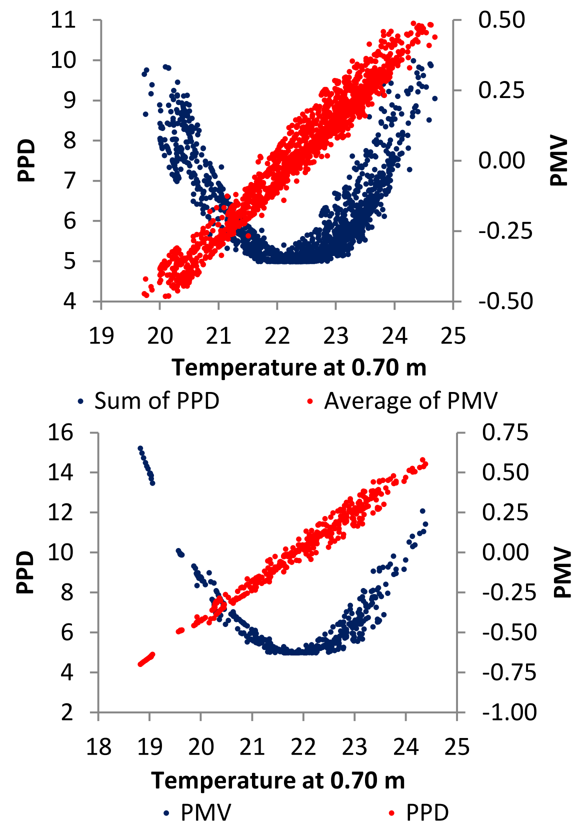
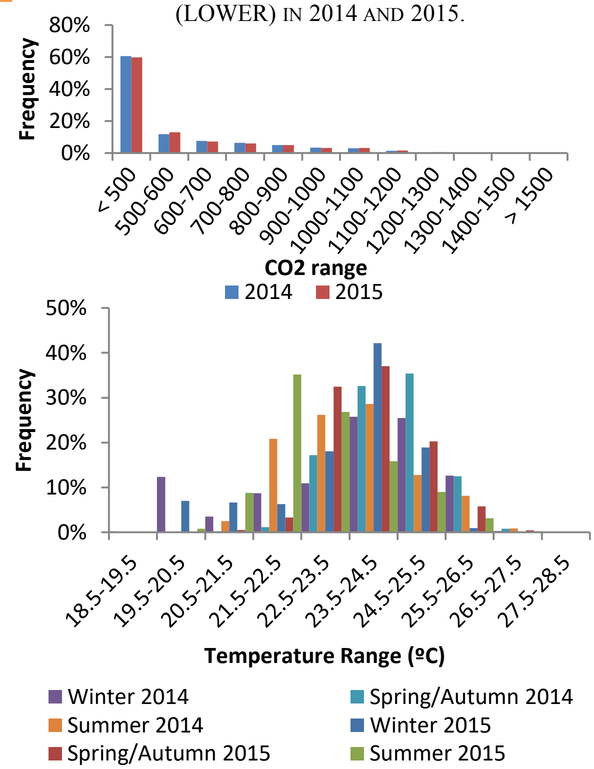


Fig.12 CO2 Frequency for the occupied hours (upper) and temperature range frequency (lower) in 2014 and 2015.



8. Performance Simulation

To understand the system behaviour and propose improvements, the seminar room was simulated using IESVE and calibrated using monitored data. Occupancy levels in the seminar room depends on the academic schedule when students have lectures between 8:00 and 21:00 and cooling mode is on during this period.

IESVE plug-in control system was improved and CO_2 data were used [8] to calculate the number of students and computers during operation until the simulation results matched the monthly hour average values of MBE and CVRSME below 10 % and 30 % respectively (Table 9). These percentages are proposed by ASHRAE [9] and research studies [10–12] using this mathematical method to establish how well this thermal model describes the variability of measured data.

Coincided weather data for the prediction period was sourced from Weather Underground [13] and introduced in simulations by updating the EWY weather file with 2015 air temperature and relative humidity data. Figure 13 (left) presents a calibrated day with heat gains and Figure 13 (right) the simulated air temperature profile, system data and room data.

Tables 7 and 8 present the design criteria and the simulation summary.

Table. 7 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	26°C
T_z , Summer Operative Temp	25°C
Overheating criteria	Adaptive Thermal Comfort
Min IAQ air supply rate	10 ls^{-1} /pers
Cooling air supply rate	As required
Noise Level Rating	

Table. 8 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	CIBSE Guide A	Define Environmental Criteria
Concept Design	EFA / CIBSE TM 52	Initial Overheating Check
Detailed Design	IES Apache	Thermal Analysis, Loads & ACR
Construction Design	IES Apache	Energy Performance

Fig. 13 INTERNAL GAINS (LEFT) AND TEMPERATURE FROM IESVE CALIBRATED MODEL AND SYSTEM DATA (RIGHT) OF 24/09/2015

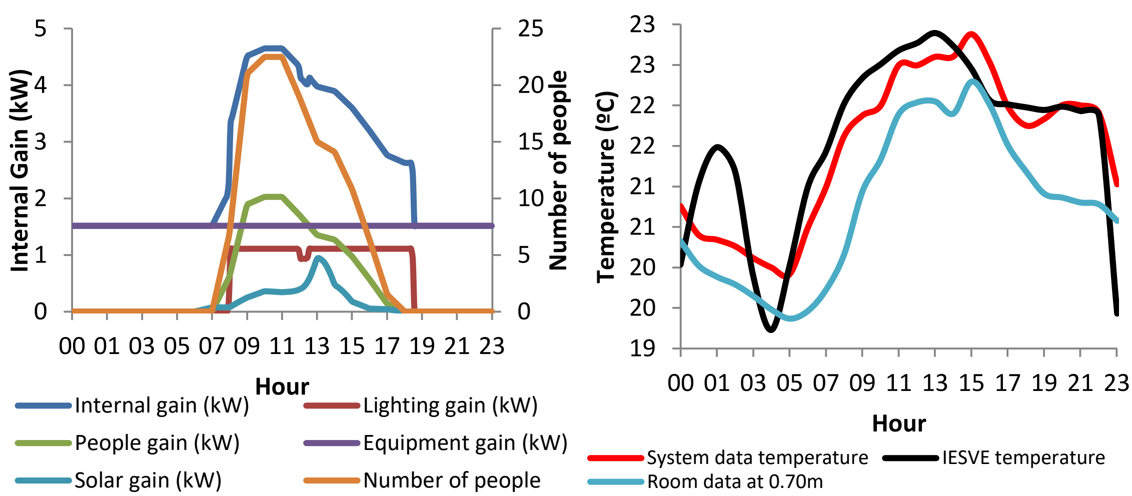


Table. 9. MBE AND CVRSME FOR 2015

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MBE	-0.59	0.68	0.09	-0.37	-0.81	-0.81	-0.29	-0.37	-0.20	-1.15	-1.21	-0.32
CVRMSE	12.93	14.84	2.10	8.49	18.27	18.28	6.76	8.38	4.67	26.33	27.15	5.81

9. Energy Performance

CoolPhase includes a variable speed fan and motors to control the dampers resulting to low overall energy consumption (see Table 10). Electrical energy consumption was 91.76 kWh (0.78 kWh/m^2/annum) in 2014 and 78 kWh (0.67 kWh/m^2/annum) in 2015 [14]. In monetary terms, this will cost less than £10 per year (based on 2015 cost average of £0.104 per kWh for a medium size building [15,16]. Simulations with IESVE show an energy demand of 8.83 MWh to maintain the same internal conditions. Therefore, the energy used by CoolPhase is a small fraction of the energy required by an AC system (the exact saving is dependent on the AC system and its COP). Simulated energy use for 2015 compared with the IESVE calibrated model shows a difference of 8.6% (or 7.08 kWh), indicating that the calibrated thermal model fairly predicts the energy demand by CoolPhase.

Performance improvement based on thermal simulation

With the calibrated model, parameters in IESVE plug-in can be adjusted and improvements on system performance can be tested with confidence. By increasing the airflow at each temperature set-point (Table 11), the percentage of temperature inside the Summer, Autumn/Spring and Winter set-point is increased. For the Summer period, temperatures are inside the set-point range (22 °C± 0.5K) in 43.6%, an increase of 14.2% compared to the calibrated model. The autumn also increased 12.3% the frequency on the set point temperature (23 °C ± 0.5K) and temperatures above 24.5 °C had a significant reduction of 27.7%. During winter, temperatures were in set point of 24 °C (± 0.5K) for 69.6% of the time, an increase of 3.7%. These results are shown in Figure 15 where the temperature is presented in terms the frequency with 1 °C interval. When the whole year is considered, the calibrated model present temperatures inside the season set-point range for 37.4% and the improved model 47.4%. This increase of approximately 10% represent an increase of 44 kWh per year (or 51.4%) compared to calibrated model or 50.8 kWh (or 64.5%) compared to measured data (Table 10).

These results are consistent with estimates by the Ventilative cooling potential tool (Figure 14) which indicate that for the location and type of building increased ventilation rates can provide internal comfort for most of the year.

Table 10 ENERGY DEMANDED BY COOLPHASE DURING THE YEAR (KWH)

	2014	2015
Cool-phase	91.76	78.74
Calibrated model	-	85.52
Improved model	-	129.52

Table 11 ENERGY DEMANDED BY COOLPHASE® DURING THE YEAR

Set-point (°C)	Coolphase Air flow (l/s)	Improved Air flow (l/s)
22	100	175
23	140	210
24	175	240
25	210	260
26	240	300
>26	260	300
Purge	300	300

Fig 14 VENTILATIVE COOLING POTENTIAL

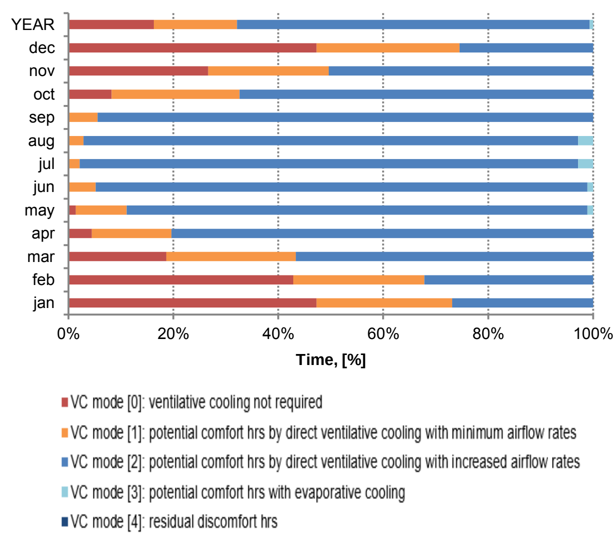
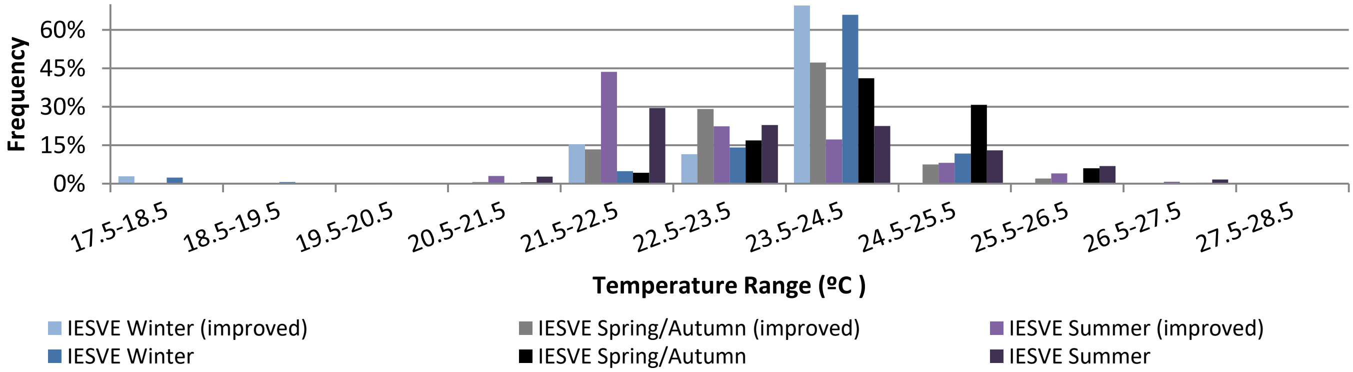


Fig. 15 FREQUENCIES OF IMPROVED AND CALIBRATED MODEL ON IESVE FOR EACH SEASON FROM 8:00 TO 21:00



Air Flow Simulation

A CFD analysis [17] was conducted to examine if areas in the room deviate from thermal comfort requirements. A 3D model of the room was generated and the results for the day of 24/09/2015 at 15:00 are presented as an example. Heat gains from computers (11) and students (14) at 15:00 were extracted from IESVE profile (Figure 13) and introduced in ANSYS FLUENT [18] as a boundary condition. Results on a seating level (0.70m) are presented in Figure 15 and 16 and shows an average temperature of 24.2 °C, 2.3 K higher (or 10.5%) from room data at the same height. This is a reasonable result due to occupants ability to open windows and doors at any time and phenomenon such as night cooling are not considered in this CFD analysis. Furthermore, the indoor environmental modelling chapter of ASHRAE fundamentals [19] points that a difference of 20% could be considered excellent for complex flow problems. Figure 15 also shows that at 0.70m, no thermal discomfort is expected due to a uniform temperature. Air velocity contours show a range of 0.1 – 0.2 m/s close to air inlet velocity at seating level. These snap shot results give an indication that no discomfort locations exist across the whole space.

Fig. 16 CROSS SECTIONS (BB AND DD - DIFFUSER LEVEL AND CC AND EE – EXHAUST LEVEL) OF THE ROOM SHOWING RESPECTIVELY TEMPERATURE AND AIR VELOCITY

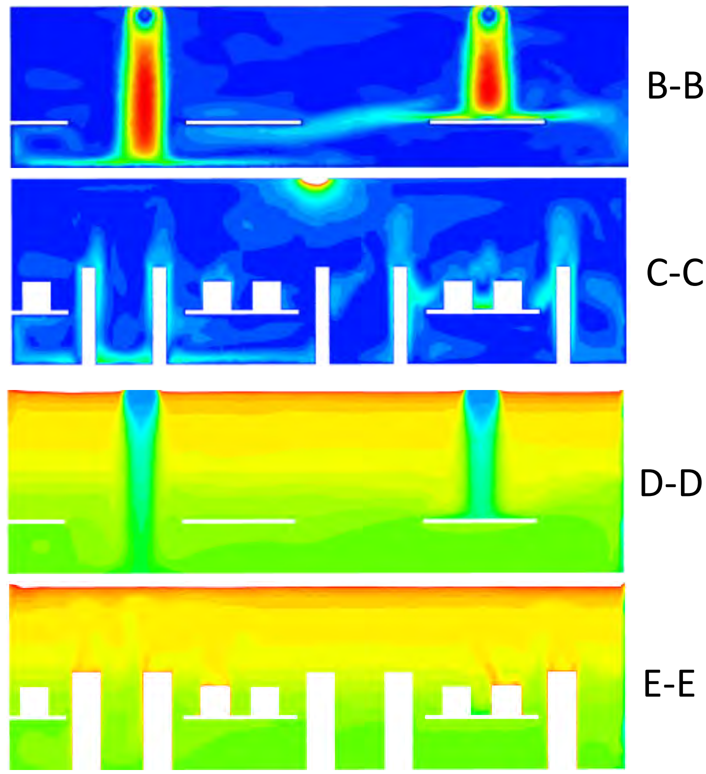
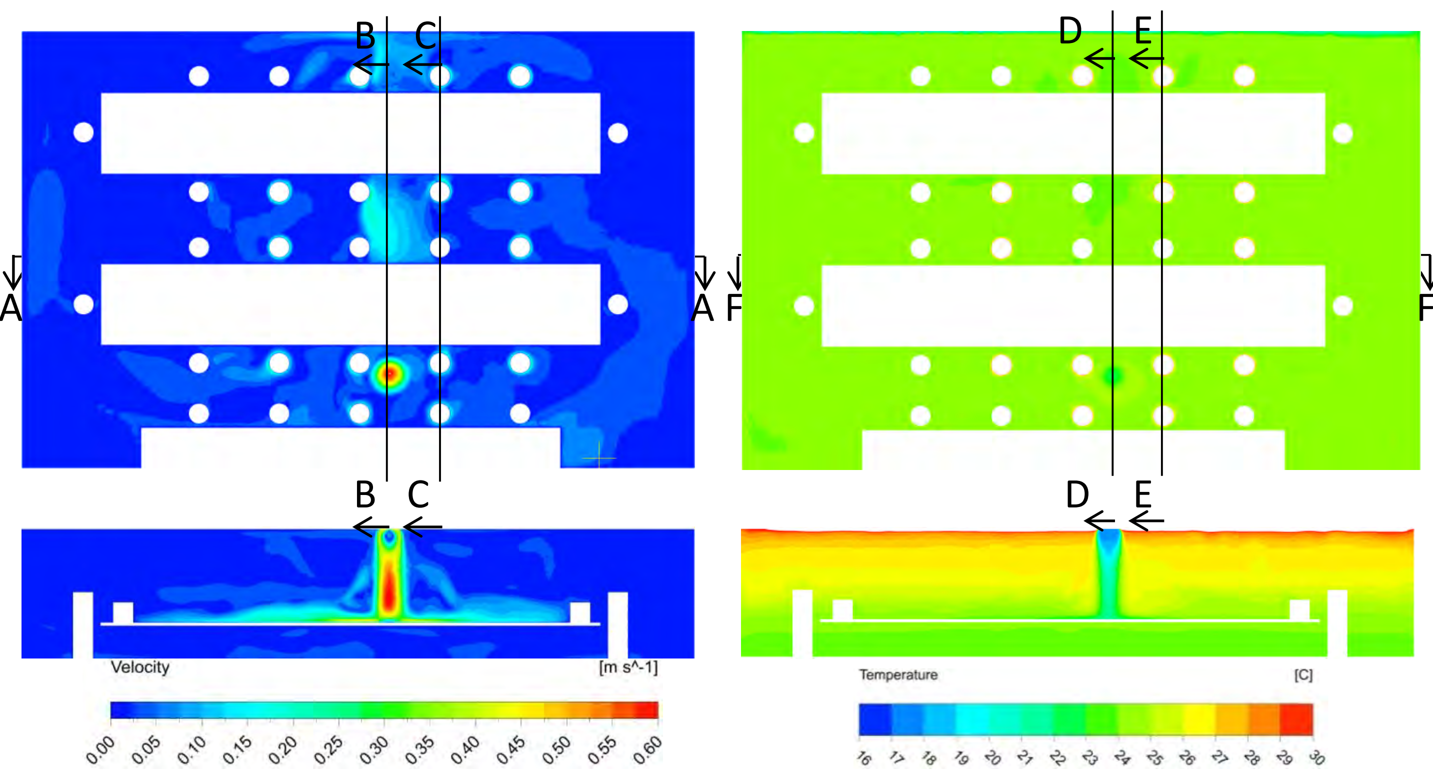


Fig. 17 AIR VELOCITY AND AIR TEMPERATURE IN TWO SECTIONS OF THE SEMINAR ROOM AT 15:00 OF 24 SEPTEMBER 2015



10. Lessons Learned

10.1 Summary

This case-study presented a Ventilative cooling system that can be suitable for newly built and retrofit applications. It uses a component called CoolPhase by Monodraught Ltd which consists of a mechanical ventilation system with PCM thermal batteries that utilise night cool air for solidifying the PCM which in turn cools recirculated or external air during its melting phase. The case-study is a retrofit application and the system was installed in the existing plenum of the space with access to outside. The system was sized for the specific application of the presented seminar room with internal heat gains of 60W/m2 and modest solar gains through the windows. The system can be installed easily and its capacity and controls were able to provide indoor air quality and thermal comfort in the space under the external weather condition of West England which is characterised by relatively low cooling requirements during the summer season. Detailed monitoring of the space and CFD analysis indicates that the system can provide acceptable thermal comfort throughout at occupant level.

10.2 Detailed list of lessons learned

Table. 12 KEY LESSONS LEARNED **DESIGN AND CONSTRUCTION**

Item	Lesson	Importance
1	Type of space and use	Determines internal heat gains and therefore choice of the system
2	Reliable sizing tools are needed which consider both the use of the space (internal heat gains and variability) and external weather patterns	Correct PCM thermal battery capacity for needs
3	Availability of components for the space configuration	Installation with minimum disruption for retrofit applications
4	Client's brief with specifications of acceptable levels for IAQ and thermal comfort	Country specific regulations or client's aspirations can be considered at the design stage
5	Client's expectation of capital and operational costs	Influence on system selection

Table. 13 KEY LESSONS LEARNED **OPERATION / POST OCCUPANCY**

Item	Lesson	Importance
1	Monitoring of system outputs during operation	Control the system according to demand
2	Client's expectations of system's maintainability	System controls can be specified according to expectations and maintenance expertise
3	Users' expectations of controllability	Controls can be designed to give flexibility to occupants
4	Users' possible adaptability to the space: This is possible in some spaces such as offices but not in others such as classrooms with fixed numbers and operation scheduling	Improved environmental and energy performance
5	Post occupancy evaluation and simulations using the original design tools can be used to improve performance	Improved environmental and energy performance

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11.2 Key Contacts

Table. 14 Key Project Contacts

Company	Role	Contact
Brunel University	Case-study research team	Thiago Santos thiagosantos@brunel.ac.uk / thiagosantos@ipojuca.ifpe.edu.br Maria Kolokotroni Maria.kolokotroni@brunel.ac.uk
Monodraught Ltd	System design and installer	Nick Hopper nick.hopper@monodraught.com
	Building Owner	To be added

1.1 Introduction

Living Lab is the first accomplished Zero Emissions Building (ZEB) under the Research Centre for Environmentally friendly Energy (FME) ZEB, placed in Trondheim Norway. It was finished in 2014 and first occupied in 2015. Living Lab is 100 m^2 single family house realized with state-of-the-art technologies for energy conservation, measurements and renewable energy source exploitation. It is planned that the building should be a test place where the heating can be supplied by space heating, radiators or ventilation and the same applies for ventilation where demands can be covered by only natural ventilation, only mechanical ventilation or by hybrid ventilation. The ventilation is designed as mixed-mode hybrid system with mechanical balanced ventilation. Supply jets are located in the living room and in the bedrooms; exhaust in the bathroom and kitchen. A heat wheel unit with nominal efficiency of 85 % and an electric back up coil capable of warming up the inlet air up to 40 °C are installed. It is built to demonstrate how CO_2-neutral constructions can be realized in the Nordic climate and also to conduct research on how occupants interact with the technologies in low-energy dwellings. Figure 1 shows the building. All the windows have monitored opening and can be automatically controlled. The sliding doors in the rooms and kitchen can be opened but are not monitored

Fig.1 LIVING LAB

Table.1 KEY INFORMATION ABOUT BUILDING

Location	Trondheim, Norway
Building Type	Residential Building
Retrofit (Y/N)	N
Surroundings (Urban / Rural)	Urban
Ventilative Cooling Strategy	Hybrid
Year of Completion	2014
Floor Area (m^2)	100
Shape Coefficient (m^2/m^3)	0.88
Openable Area to Floor Area Ratio (%)	35%
Window to Wall Ratio (%)	6.8%
Sensible Internal Load (W/m^2)	The load varies with the different test run
Climate Zone (KG) (words?)	Dfb
No. of Days with T_e max > 25	0
Cooling Season Humidity	100
Heating Degree days (Kd)	3956 (Tb 17)

1.2 Local Climate

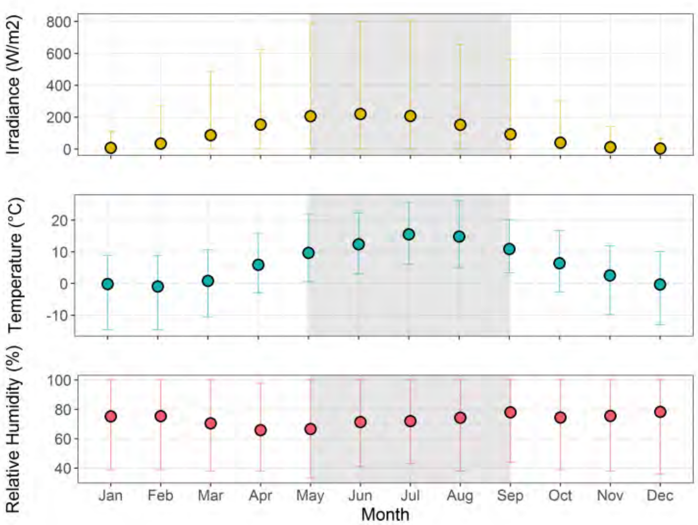

Fig.2 MEAN, MAXIMUM AND MINIMUM EXTERNAL CONDITIONS IN TRONDHEIM USING TMY3 FROM METEONORM 7 (COOLING SEASON SHOWN SHADED)

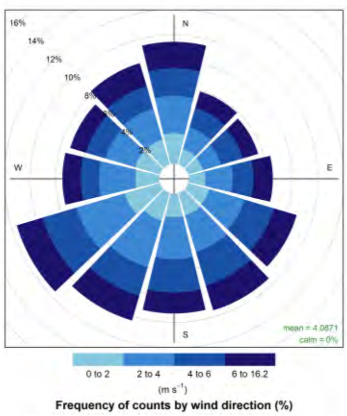

Fig.3 WIND ROSE FOR TRONDHEIM

2. Building Information

2.1 Description

The Living Lab is a single family house representative of the Norwegian residential building stock regarding typology (detached, single family house) and surface. It integrates state-of-the-art technologies for energy conservation and solar energy exploitation. It has two sleeping rooms and one loft- room. The living room is divided in working area towards the North and sitting room and kitchen towards the South. The construction system was also chosen so that, if necessary, building equipment and components can be easily changed in case new technologies are to be tested. The building construction has well insulated envelope. Walls, floors and roofs have a conventional wooden-frame structure with a double layer of rock wool insulation with a total of 40, 40 and 45 cm respectively. The Living Lab has been designed to have a low energy demand during its operation. Different solutions and building equipment are planned to be installed, so that several options can be tested within the same building.

Table.2 Building Properties

Property	Unit	Value
Occupant density	m^2/p	20
Hours of occupancy	h/week	16
Sensible Internal Load	(W/m^2)	-
U-value windows (south façade)	W/m^2K	0.65 / 0.69 (if ventilated)
U-value windows (north façade)	W/m^2K	0.97
Window g value	(-)	0.35-0.69
Wall U-value	W/m^2K	0.11
Roof U-value	W/m^2K	0.10
Floor U-value	W/m^2K	0.10
Thermal Mass (ISO 13790)	-	Light
Window to Wall Ratio	%	17
Air-tightness (@50 Pa)	1/h	0.5
Shape Coefficient (1/m)	%	35

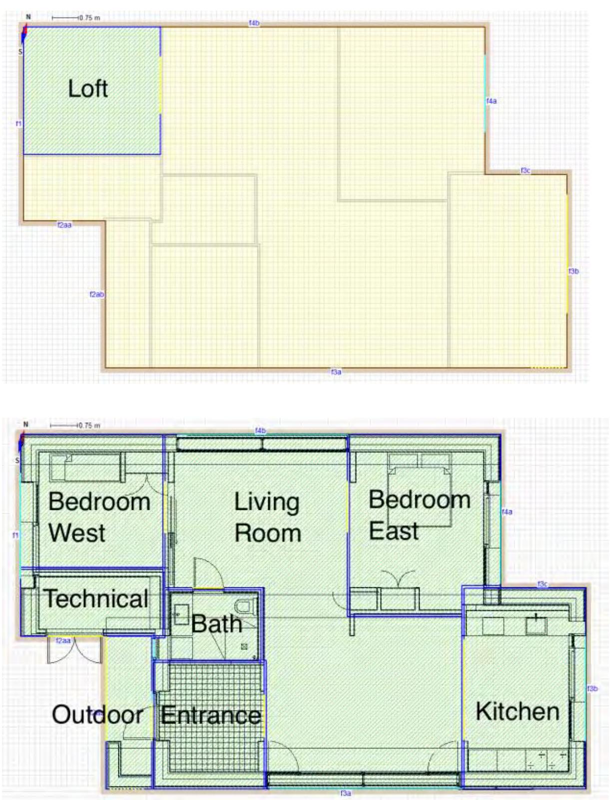

Fig 4. Living Lab layout Architectural drawing.

Table.3 Design influences

Parameter	Level of Influence
Initial Costs	•
Maintenance Costs	•
Energy costs	⬤
Solar Loads	⬤
Internal Loads	●
External Noise	•
Internal Noise Propagation	●
Air Pollution	•
Rain Ingress	⬤
Insect prevention	•
Burglary prevention	•
Privacy	•
Air Leakage	⬤

3. Energy Systems

The Living lab is a research facility where the supply systems are triplicated. The house renewable resources are a ground source heat pump and solar panels. In addition, the heat can be supplied by space heating, radiators and/or ventilation. The goal is the comparison of different solutions and their effect in achieving the ZEB.

3.1 Heating System

The heating system of the Living Lab is triplicated to give the possibility to test several possibilities. The energy sources are electricity, used directly or in a horizontal-collector-heat pump and solar energy. The heat distribution is air borne by means of the ventilation (also for the air cooling) and water borne by means of radiator and space heating. The system comprises a 3.2 kW heat pump, 4.2 m^2 of South façade mounted solar panels, a 400 l accumulation tank and two 3.0 kW electrical back up heater

3.2 Electrical Power Supply (PV, wind turbine & Microgrid)

The electricity is provided to the building by the PV solar panels. The two slopes of the roof are covered with a building-integrated PV system . The total installed power is 12.5 kWP and the efficiency of the polycrystalline silicone cells are approximately 16 %. The energy converted by the PV system is dimensioned to cover the energy needs of the building and to balance energy embedded in the materials and components used to realize the Living Lab. Very different consumptions have been measured depending on the users, as Figure 7 shows.

Fig. 5 DRAWINGS SHOWING PLACEMENT OF WINDOWS AND DOORS AT THE LIVING LAB

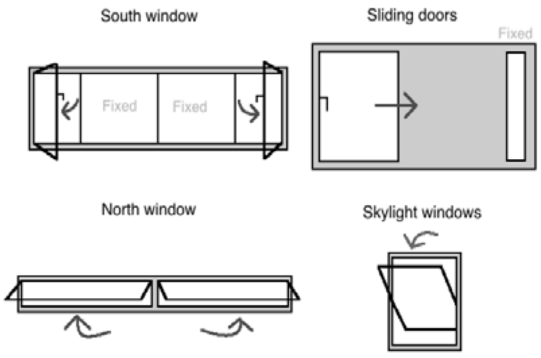

Fig. 6 DETAIL OF WINDOW OPENING

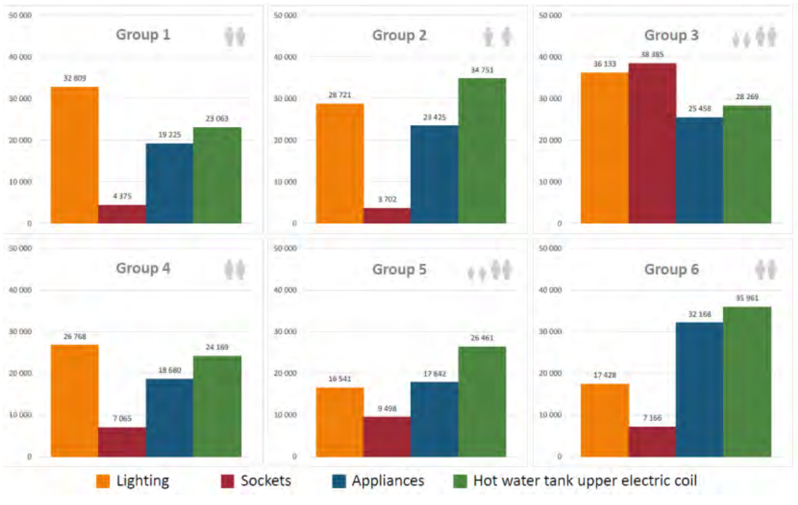

Fig. 7 DETAIL OF ENERGY CONSUMPTION OF DIFFERENT HOUSEHOLDS LIVING IN THE LIVING LAB (SKEIE, 2016)

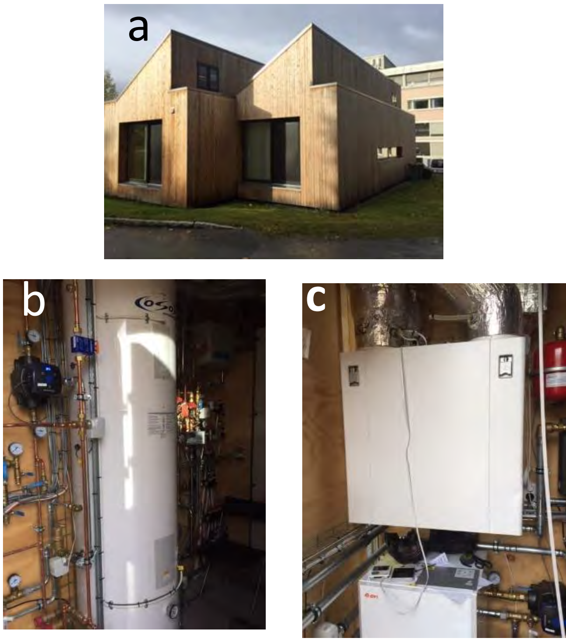

Fig.8a)EAST SIDE , B)ACCUMULATION TANK, C)AHU AND HEAT PUMP

4. Ventilative Cooling

4.1 Principles

The building can be naturally ventilated by single sided window opening and cross ventilation as shown in Fig 9. The combination of the opening of WDW, WN1 And WN2 with WDE (in Fig 11) provides the biggest of airflow rates as a result of the buoyancy effects. It has been observed that probably due to the triangular shape of the roof even when wind is flowing from North, the WDE placed on the higher level acts as outlet. Provided occupancy the combination WDW, WN1, WN2 and WDE with the kitchen door opening is the solution that gives the highest airflow rates. The opening of the South window does not seem to sensibly improve the cooling. During summer days with high solar irradiation, the hybrid mode is to be run with a concurrent mechanical ventilation and window opening.

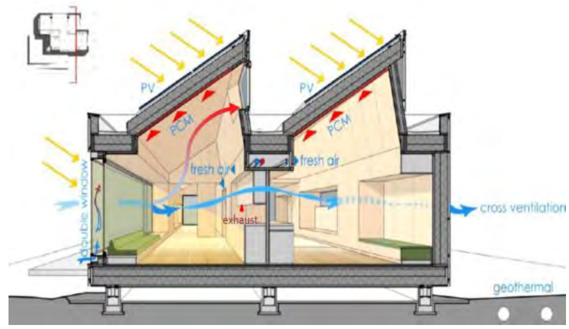

Fig.9 VENTILATIVE COOLING PRINCIPLE

4.2 Components

On the North side an oblong window is implemented (Fig 10 a). It is constructed with hinges at the top, and opens to a maximum angle of 39º. On the West and East side there are glass sliding doors (fig 10 b). There are two sets of rooftop skylight tripled glazed windows facing north (fig 10d). They open horizontally to a maximum angle of 30º. The South windows open a maximum of 37º. See Fig 10c and description in Table 4.

Table. 4 COMPONENT C :CAPACITY DIMENSIONING

Parameter	Value
Type (As per SOTAR)	Double facade window
Free opening area	0.33 m^2
Discharge Coefficient (Cd)	0.4
Overall Dimensions (1 louvre bank)	10 m^2
Porosity (A_w/A_f)	0.24

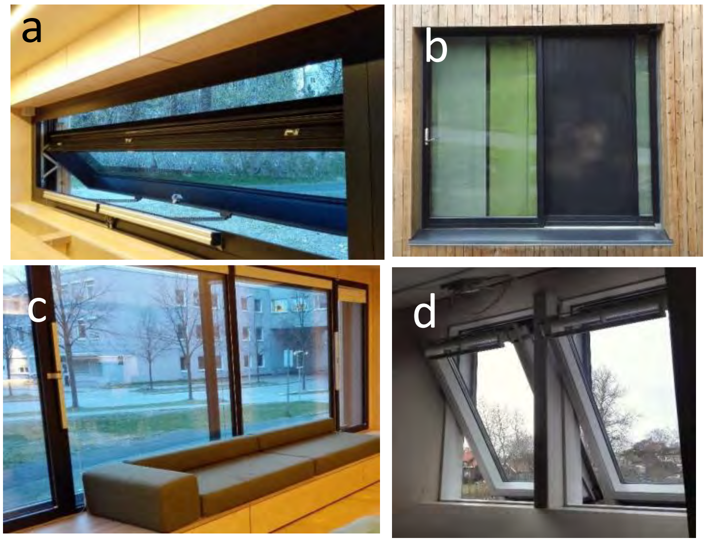

Fig. 10 PICTURES OF THE WINDOW OPENINGS

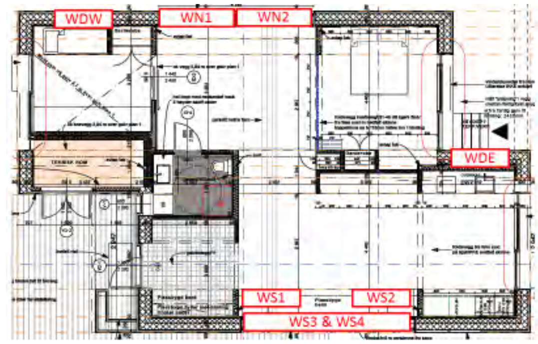

Fig. 11 DETAILS OF THE PLACEMENT OF THE WINDOWS

5. Control Strategy

5.1 Control Strategy Overview

By writing time, there is no fixed ventilation control strategy and the ventilation is run constantly. Optimized controls have been developed for static and dynamic controls as presented in Table 6. For the VC project, two strategies were considered, fully natural and hybrid. The principle for airflow distribution tested varied from cross, to one sided ventilation. For the regulation of the window opening, different controlled were tested On/off, P, PI and the window degree of opening depended in many factors and pointed out in Table 6

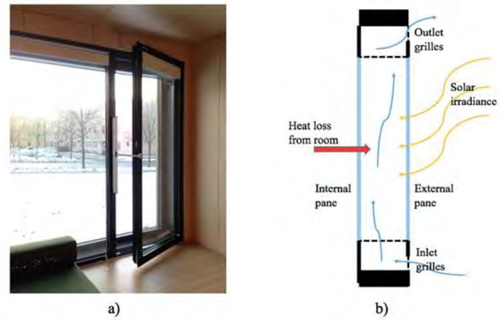

Fig. 10 A) THE SOUTH WINDOW, PHOTO SOLVEIG BLANDKJENN, B) WINDOW PRINCIPLE

Table. 6 CONSIDERATIONS FOR CONTROL STRATEGIES

Control tested	Window opening		Mechanical ventilation
Natural ventilation	On-off PI controlled	Day /night Temperature(in/out) Outdoor weather conditions (rain, wind, sun) CO_2	--
Hybrid Control	On-off PI controlled	Day /night Temperature(in/out) Outdoor weather conditions (rain, wind, sun) CO_2	Concurrent On/off control Change-over On/off control Natural ventilation PI-control Concurrent PI-control Change-over PI-control

5.2 Control Strategy Description

Six control strategies have been used to determine thermal comfort and energy consumption. The opening of windows has been done in combination with mechanical ventilation. In case of having too low outdoors temperatures hygienic ventilation rates are ensured. For the thermal comfort, the number of hours with overheating and under cooling have been analyzed. According to the analysis of the results, the most influencing factors on the need for ventilative cooling at the Living Lab were: solar radiation, outdoor temperature and occupancy. The wind does not appear to have influence on the need for cooling, but influences the efficiency of ventilative cooling. High air velocities when windows were fully open meant higher air velocities in the building.

The results from the simulations implied that there will be a severe risk of overheating in Living Lab if no active or passive cooling techniques are applied. The results showed nonetheless that ventilative cooling can prevent overheating without significantly increasing the energy demand.

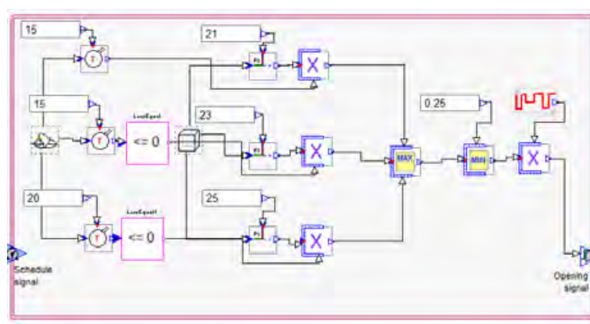

Fig. 11 CONTROL STRATEGY OF WINDOW OPENING

Table. 7 SIMULATION OF ENERGY CONSUMPTION FOR PI WINDOW CONTROL

Energy	Concurrent Mechanical and PI window control	Change-over Mechanical and PI window control
Recovery [kWh]	4808.50	4137.4
Zone heating [kWh]	5470.4	6038.3
AHU heating [kWh]	243.0	177.9
Fan energy [kWh]	1094.9	943.7
Lighting [kWh]	1083.0	1083.0
Equipment [kWh]	1116.0	1116.0
Total energy demand [kWh]	9007.0	9358.9

6. Design Simulation

6.1 Summary

The design of the Living Lab was done according to constrains of the Solar Decathlon. Afterwards in the concept design phase the energy performance simulation program SIMIEN was used. For the phase of detail description the company Prosjektutvikling midt Norge was in charge of making the drawings and they used SIMIEN as well. For the evolution of performance IDA ICE was used.

Table. 8 DESIGN CRITERIA

Parameter	Value
T_e , Summer External Temp	25
T_z , Summer Operative Temp	26
Overheating criteria	T>26
Min IAQ air supply rate	$7 ls^{-1}$/pers
Cooling air supply rate	-
Noise Level Rating	

Table. 9 DESIGN STAGE SIMULATION SUMMARY

Stage	Tool	Function
Scope Development	NS 3700	Define environmental criteria/Energy use and IAQ
Concept Design	SIMIEN	Dimensioning of energy systems
Detailed Design	IDA ICE	Dimensioning window opening, optimization of controls
Performance evaluation	IDA ICE	Thermal comfort and energy use

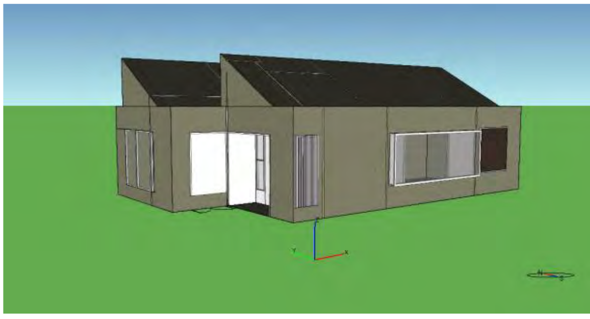

Fig. 12 IDA ICE SIMULATION MODEL

6.2 Simulation of overheating risk

Simulations show that for years with high solar radiation, risk for overheating is happening often as a result of the high level of the building insulation. Another fact is that if windows are not precisely controlled, problems with overcooling are very important as well. Table 9 shows the results for different window openings

Table. 9 EFFECT OF THE WINDOW OPENING IN THE REDUCTION OF DISCOMFORT (BLANDKJENN, 2016)

	Hours of thermal discomfort				Heating and cooling energy	
	Living room [h]	Building total [h]	Decrease living room	Decrease building total	Value [kWh]	Increase compared to closed windows
No openings	105	303			126.2	
Mech. Cooling	0	0	100 %	100 %	341.8	171.8 %
S12.5%, N25%	17	57	83.8 %	81.2 %	139.4	10.5 %
S12.5%, N50%	15	47	85.7 %	84.5 %	144.9	14.8 %
S25%, N25%	15	48	85.7 %	84.2 %	138.9	10.1 %
S25%, N50%	13	38	87.6 %	87.5 %	145.1	15.0 %

6.3 Simulation of ACR

The minimum measured ACH are 0.5 while using natural ventilation the ACH varied very much locally, Fig 13 a and b show the effect of window opening in draught rates and temperature differences between indoor and outdoor

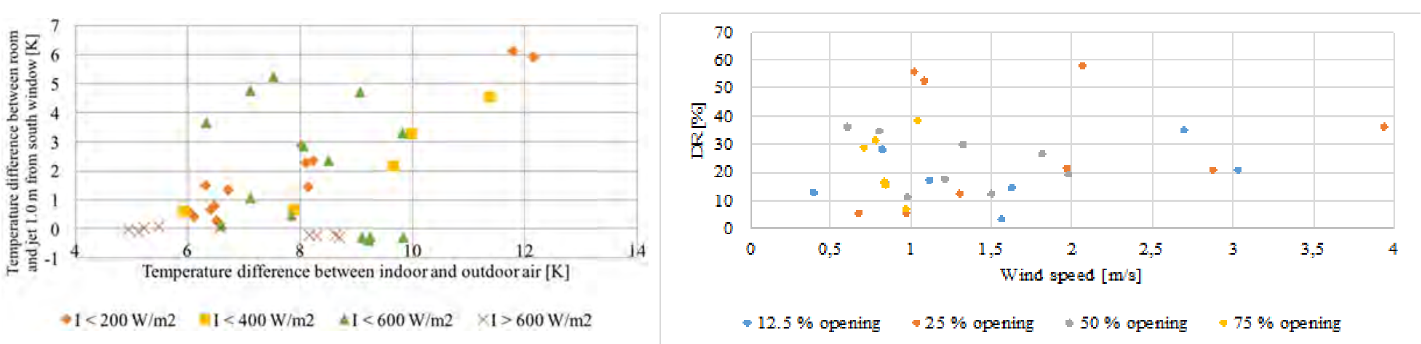

Fig. 13 a) TEMPERATURE DIFFERENCES BETWEEN THE JET AND THE ROOM B) DRAUGHT RATE FOR DIFFERENT WINDOW OPENINGS, BOTH (BLANDKJENN, 2016)

7. Performance Evaluation

7.1 Measurement equipment

Indoor air temperatures are measured in every room of the Living Lab, at the height of 1.6 m from the floor. In the living room and in the studio room, temperature and RH stratification are also measured (in 5 levels: 0.1, 0.8, 1.6, 2.4, 3.2 m from the floor) with accuracy ± 0.1 K and ± 3%, for temperature and humidity ratio, respectively.
CO_2 concentration is also measured in every room with accuracy ± (70 ppm + 5%).
Motion sensors are installed in every room. The position (open/closed) of all the windows are continuously recorded by means of magnetic alarm switches, which give a potential free changeover contact signal when the window is open.
As long as the mechanical ventilation and heat recovery system are concerned, the enthalpy flux will be calculated during the acquisition, based on the measurement of the air temperature, of the humidity ratio and of the air speed in the ventilation ducts. Accuracy of the devices is ± 0.1 K (temperature) and ± 3 % (humidity ratio) Four KFTF-U Pt100 are installed (supply and extract ducts in the inside, inlet and exhaust ducts in the outside, before the heat recovery system), while two KLGF-1 are planned to be mounted in the inside ducts (supply and extract).

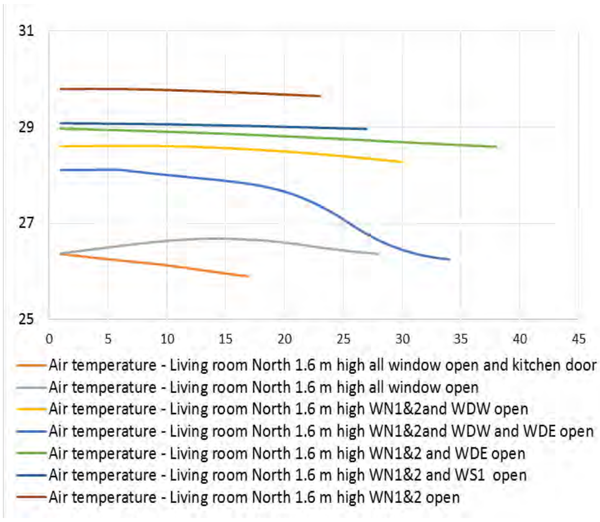

Fig. 14 INDOOR AIR TEMPERATURE IN NORTHERN LIVING ROOM WITH CONCURRENT BALANCED AND NATURAL VENTILATION (X AXIS ARE TIME AND Y TEMPERATURES)

Table 9 HOURS EXCEEDANCE WITH NO SHADING USED

Parameter	Year
Total Hours > 25°C	280
Occ Hours > 25°C	199
Total Hours > 28°C	40
Occ Hours > 28°C	22

7.2 Internal Temperatures

Figure 15 and 16 show the temperatures in the warmest place of the Living Lab for different strategies of window opening with and without mechanical ventilation. In a warm day, the cooling with only windows opening is not sufficient to reduce temperatures unless the right windows are opened. There is also a big gradient of temperatures between the North and South sides of the living room of up to two degrees for many of the measured periods with both natural and hybrid ventilation. For warm days opening the WS1 with only natural ventilation does not seem to encourage the cross ventilation and on the contrary results on increased indoors temperatures.

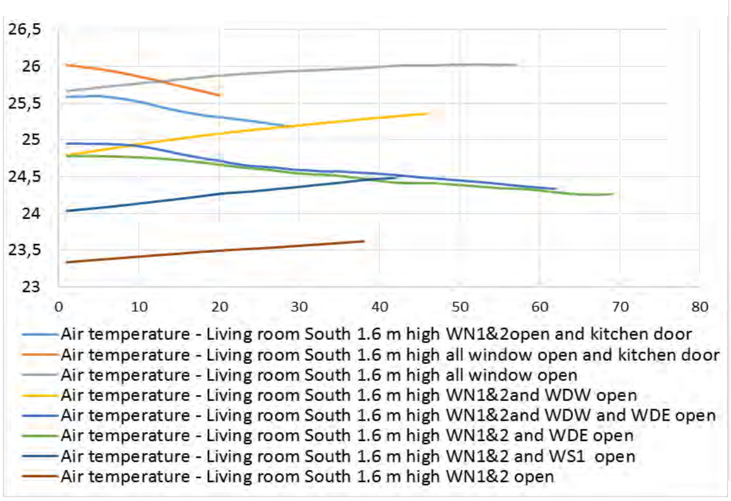

Fig. 15 INDOOR AIR TEMPERATURE IN SOUTHERN LIVING ROOM WITH NATURAL VENTILATION AS A FUNCTION OF TIME (MINUTES)

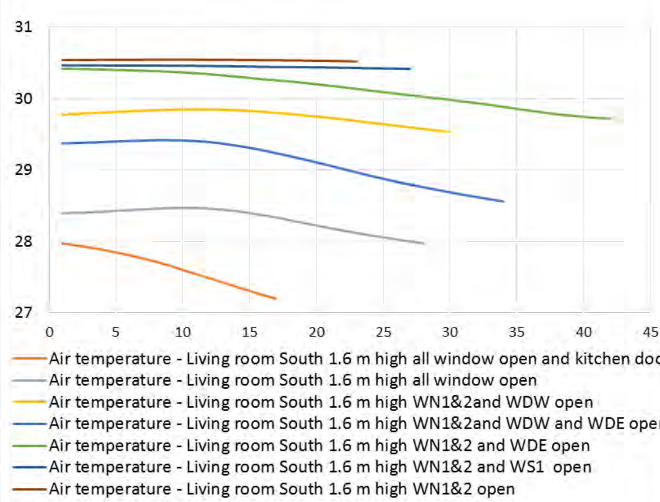

Fig. 16 INDOOR AIR TEMPERATURE IN SOUTHERN LIVING ROOM WITH CONCURRENT BALANCED AND NATURAL VENTILATION AS A FUNCTION OF TIME (MINUTES)

7. Performance Evaluation

7.3 Comfort and air velocities

In summer time, when outdoor temperatures are high, the risk for overheating and thermal discomfort is as described in Table 9. This table shows the results when no shading is used. In such houses, when opening the windows, temperatures are reduced. There is normally a zone (orientation) where the sun is not shining and outdoor air is colder than indoor air. When the outdoor temperature drop and the sun is still shining there is still risk of overheating. In this case the windows opening have to be done in a controlled way to avoid overcooling. Figure 17 shows an example of windows opening and high air velocities during autumn. Overcooling has to be thoroughly thought in order to avoid overcooling.
Air velocities inside the house for only natural ventilation are measured very low between both sides of the building even when the wind speed is over 5 m/s. Further research is needed to determine the air distribution on the building during very warm periods.

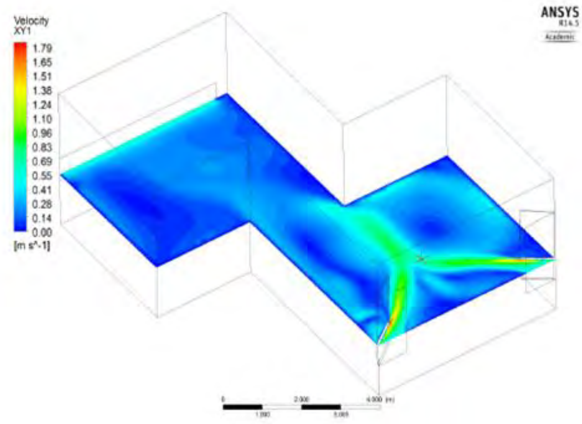

Fig. 17 Example Horizontal air velocity variation at height 1.5m. Inlet velocity 0.5m/s

Many Norwegian users want low temperatures in the sleeping room, and Fig 18 shows the measured temperatures in the sleeping room for six occupant groups. To satisfy the wish for low temperatures, the low mixing rate in the Living lab seems to be very effective, however, for users that want higher sleeping rooms temperatures this low mixing will result in an increase in energy use for heating. For cooling, the low mixing area ensures a cooling buffer.

7.4 Occupancy Profiles

The occupancy variated very much between the occupant groups, for the simulation a standard profile for a family of two parents and two children was used, as shown in Fig 19. Real measurements show that the group that was more at home , spent double the time that the group that spend less. Their expectations regarding comfort temperatures are also different what yielded almost twice of energy use.

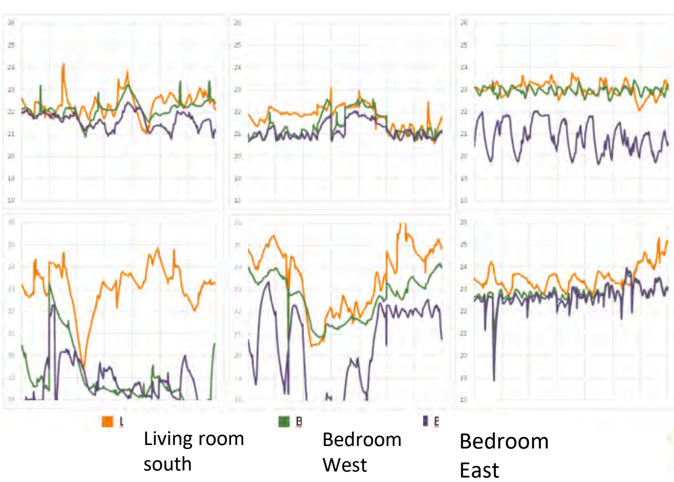

Fig. 18 Temperature in selected rooms during occupancy of 6 different households

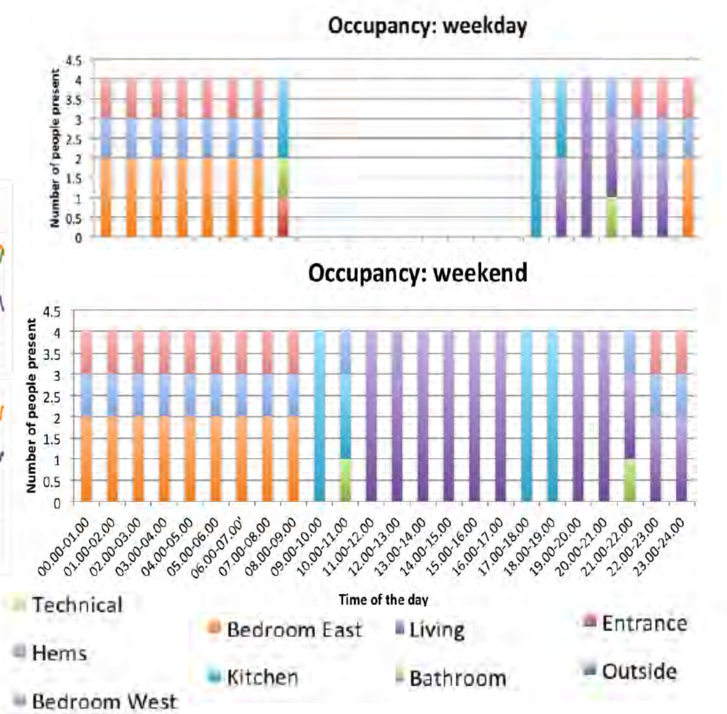

Fig. 19 Typical heating and cooling season occupancy profiles

8. Lessons Learned

8.1 Summary

The Living lab is a research facility built as a Zero Emission building. As such, the chosen solutions are not the same as those taken in a non test facility building.
There are cooling demands in the Living lab when the solar shading is not used correctly and it is warm outside. In addition, based on the result for the occupancies of 6 different households, the demands and expectations vary a lot based on the user. When the house is too warm, the ventilation proves very efficient for cooling down the Living lab. By using a carefully considered window opening strategy, the cooling demands are removed. However, given the low outdoor temperatures like in Trondheim, risk for draught should never be underestimated. Protections against overcooling have to be thought through to avoid discomfort.

8.2 Detailed list of lessons learned

Table. 12 Key Lessons Learned **Design and Construction**

Item	Lesson	Importance
1	Simulations show a severe risk of overheating in Living Lab if no active or passive cooling techniques are applied. The results showed nonetheless that ventilative cooling can prevent overheating without significantly increasing the energy demand	
2	The study found that the best way to apply ventilative cooling in Living Lab would be to implement a concurrent mixed-mode system where the window control system is only active during the day	
3	It is very difficult to design a system that will fit an uncertain number of occupants	
4	Developing an experiment building with many different interest and comments to the process and it made the project delayed , more expensive and more difficult to run	
5		

Table. 13 Key Lessons Learned **Operation / Post Occupancy**

Item	Lesson	Importance
1	Having a building that is over controlled and monitored has the challenge that the sensors have to be calibrated . Several sensors were delivered fail	
2	The differences between users expectations yields a system that is not optimized for all the cases	
3	Users are generally more satisfied when they can control their environment even is discomfort temperatures.	
4		
5		

9. References & Key Contacts

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9.1 Key Contacts

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