D 6.2 Documentation of each study case
CS5 Primary School Hötting, Innsbruck (Austria)
Delivered at M42

EUROPEAN COMMISSION

DG Research and Innovation

Seventh Framework Programme

Theme [EeB.ENV.2010.3.2.4-1]

[Compatible solutions for improving the energy efficiency of historic buildings in urban areas]

Collaborative Project – GRANT AGREEMENT No. 260162

Technical References

Project Acronym	3ENCULT
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Project Coordinator	Alexandra Troi EURAC research, Viale Druso 1, 39100 Bolzano/Italy Alexandra.troi@eurac.edu
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Documentation of Case Study 5

0.1 General Information

Location

Name and location of building	Monumental school in Hötting, Fürstenweg 13, 6020 Innsbruck, Austria; Altitude: 574m.a.s.l.; Heating days: 205 [d/a]; Heating degree days: 3047 [Kd] (mean value from consumption measurement from 2005-2011)
Legal investigation	ownership: Innsbrucker Immobilien GMBH&CO KG
Heritage administration	Landeskonservatorat für Tirol (cultural heritage authority), A-6020 Innsbruck, Burggraben 31 Tel.: +43 512 582 932DW; +43 512 582 087DW Fax: +43 512 581 915 Email: tirol@bda.at

Responsible Planner/ Architect	Architekt DI Gerald Gaigg (architectural team)
Local case study team	UIBK (scientific guidance), Innsbrucker Immobilien GMBH&CO KG (building owner), Landeskonservatorat für Tirol (cultural heritage authority)
Name and company of surveyor	Rainer Pfluger, Kai Längle, Michele Bianchi Janetti, Pavel Sevela, UIBK; Architect Gerald Gaigg
Comments	Additional information about CS 5 can be also find in D8.12 and D7.5.

General description incl. building problems	
Date of construction	1930
Architect/Artist/other persons	In 1928 the municipalities of Hötting and Innsbruck announced an architectural competition for the planned new school building. The architects Franz Baumann and Theodor Prachensky succeeded with their project, strongly influenced by the architecture of Peter Behrens and Bauhaus.
Architectural style	Modernism
Typology of building	Educational establishment
Original objective	Public school
present use	Public school
expected use in the future	Public school
Construction materials	Mixed structure - The building walls and the foundations are constructed with bricks and concrete and they are covered with lime-cement-plaster. The ceilings and the canopy are built with steel beams and concrete plates.
Construction method	Mainly as a masonry construction.
Short description of building	Location: close to the historic center of Innsbruck, nearby to the river Inn, at the west side a block perimeter residential building is situated, at the north side borders a public swimming pool, at the east side a residential building and at the south a school building will be actually erected. The building consists of cubic monolith blocks with no additional elements like bays, balconies or other ornaments, as typical for the early modernism. The wooden hipped roof is covered with a sheet metal but the roof seems to be flat from around, because the attic of the external walls covers the roof visually from below. The building walls and the foundations are constructed with

	bricks and concrete and they are covered with lime-cement-plaster. The ceilings and the canopy are built with steel beams and concrete plates. The school contains 6 stories and the maximal height is 20m. The built ground area is 1600m² and the treated floor area in total is about 4090m².
Number of Axes	1
Shape of roof	Hipped roof
Internal access	Central access
Status quo	High heating energy demand (about 130 kWh/(m²a)) and severe overheating problems due to large unshaded glazing areas. Some of the classrooms cannot be used during summer season. Air quality problems and low thermal comfort (draft risk and low surface temperatures in winter) are further problems, which have to be solved.
Overall conservation status	The building kept the genuine building envelope, disposition. Only minor changes on building elements has appeared. In the years following WW2 the school was enlarged on the eastside.
Actual European energy standard	Building was not certified according to EPBD. The measured energy consumption for heating was 124,4 kWh/m²a
building problems with regards humidity	See below section 1.2
building problems with regards salts	Not known.

Planned activities within the project	
Diagnosis	• Building survey and adaption of old plans • Infrared thermography • Air-tightness-test • Analysis of actual ventilation situation • Monitoring of artificial light consumption • Thermal bridge calculations • Calculation of annual heat demand by PHPP • Calculations of refurbishment variants
Planned solutions	• Development of new ventilation concept (details in WP3)

	• Prevention of condensation at beam end of the concrete brick ceiling (internal insulation) • Enhanced daylight autonomy by daylight redirection • Optimization of heating control • Minimal invasive external or internal insulation • Improvement of the room acoustic
Monitoring system	• Thermal comfort: Draft risk (air velocity) • Temperature (radiation and air temperature) • Relative humidity • O/C Status of windows and doors • Visual comfort: Artificial light situation • Daylight situation • Indoor air quality: CO2 • BMS (building management system) of CS5: Lighting and shading using BMS (computer located at school) • Self-controlled ventilation by motion and time schedule (after application of the whole overflow concept, maybe BMS is applied) • BMS is considered for the lighting and shading after extension to the entire building, also for other HVAC (Ventilation, Hot water production, PV, Heating)
Simulation	• Thermal bridge simulations • Hygrothermal simulations at the beam end • Simulations to analyse the distribution of the supply air (new ventilation system) with CONTAM
Transfer to urban scale concept	The Hottinger school will be part of the EU SMART CITY project called SINFONIA. Several energy eff. solution such as internal insulation, ventilation system, window integrated shading and similar, can be applied on other buildings (schools and dwellings) within the project framework.
Others	Within the 3ENCULT project were applied two overall ways of approach how to come up with energy efficient solutions for cultural heritage: the top-down as well as the bottom up approach. Both approaches have pros and cons. The first, more general approach covered a wide range of universal solutions, concepts and possibilities, on the other hand, the individual case studies were necessary to demonstrate and

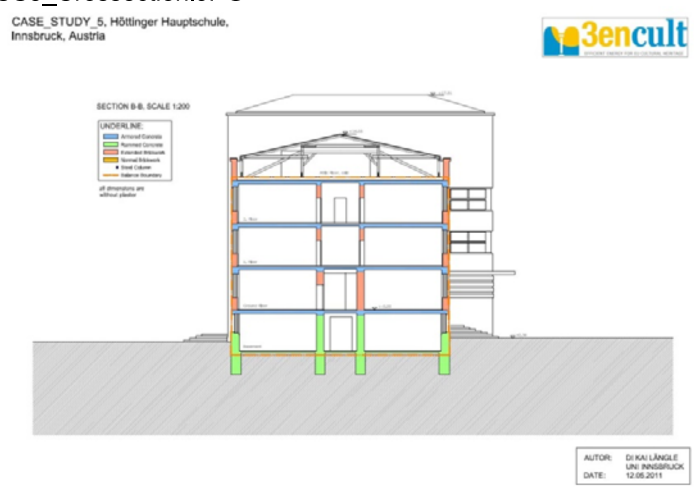
	validate the generalized concepts for a specific building and environment. The two approaches may be summarized as follows: The top-down approach looks for solutions based on the evaluation of impact analysis as well as the comprehensive diagnosis of built heritage for sustainable intervention. This approach may start either from a wide scale by integration in urban sustainability concepts and strategic environmental assessments considering also the building energy issue, or from a smaller scale involving historical and structural investigations and diagnosis of investigated building assessed by inventory systems, such as “Raumbuch”. The issue of structural diagnosis is in close link to building physical problems, which in best case could be solved collateral with the enhancement of the energy efficiency. The bottom-up approach for the development of energy efficient solutions is to analyse specific case studies and its special needs. Tailor-made solutions for the individual needs of historic buildings can be developed, realized and monitored in real scale. The exemplary solutions are analysed and their transferability and applicability to other climates, different context of historic, architectural and conservational values is investigated in an interdisciplinary way. This chapter gives a general evaluation of the case studies and conclusions from both, the conservation point of view as well as the energy efficiency point of view. It is based on the task “Preservation issue surveillance” within the 3ENCULT project, which reinsured the conservation compatibility of the developed products and methods.

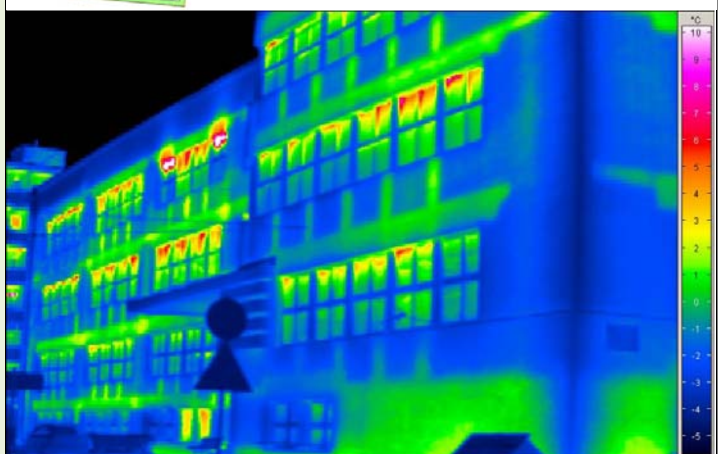
0.2 Building Assessment

Cultural Value (Specific valuable aspects)	
Architectural historical value	The building complex has both outstanding qualities as structural space and valuable details typical for its constructing-period and therefore was declared historical monument in 2008 following §2 DMSG. The definition of the different values (architectural, cultural and social) is explained in D 2.4 Position paper EIA method – The 3ENCULT methodology – FINAL (page 19)

Cultural historic value	
Context value	One main objective within the discussions between owner, architect and authorities of cultural heritage is the vision of the restored school building, the balance between restoration and adaption to the necessary demands of an up-to-date school preserving the specific atmosphere and characteristics of a building of the 30ties.
Social value	Since the opening in 1932 not only the methodologies in teaching but also the building codes and guidelines and convenience standards for school buildings have changed, the building therefore has to be adapted to fulfil these demands respecting the interests of cultural heritage.- Improving of shading, lighting, acoustic, thermal comfort and air quality- Integration of computer cabling and new technical equipment
Constraints conditions	*Exterior Insulation is inacceptable in any case. In some cases interior insulation is acceptable to make an insulating inner wall if there are no panels or other architectural details. This intervention must be removable without damaging the genuine structure.*
Others	Within 3Encult different interventions improving the energy efficiency of the building were discussed with the Austrian Authority for Cultural Heritage BDA, represented by Landeskonservator Hofrat Dipl.-Ing. Werner Jud, the IIG as owner of the building and the architect.

Documentation

diagrams/drawings	CS5_Crossection.JPG 

	 
expertises/reports	Analysis of architectural elements.pdf, Thermographie_Höttingerschule_20130313_v2.pdf

photographs/images	 

	  IMG_6497.JPG, IMG_6541.JPG, lamella radiator.jpg, IMG_6498.JPG, jupload-manual-de.pdf
publications/press	Publications (University Innsbruck) • Active overflow ventilation for refurbishing of school buildings (Pfluger, 17. International Passive House Conference) • Energy and Cost Efficient Ventilation Systems with Heat Recovery – State of the Art and Enhancement (ASHRAE)

	• Minimal Invasive Ventilations Systems with Heat Recovery for Historic Buildings (Clima 2013, Pfluger) • Messung und Auswertung zur Behaglichkeit insbesondere im Sommerfall am Beispiel der Höttinger Hauptschule (Diplomarbeit Andreas Mair) • Messung und Auswertung zum thermischen und visuellen Komfort, und Überprüfung der Grenzwerte am Beispiel der neuen Mittelschule Hötting (Diplomarbeit Michael Crazzolara) • Vergleich unterschiedlicher, innenliegender Wärmedämmsysteme bei einer denkmalgeschützten Schule (Innendämmkongress Dresden) • Building physics problems in early modernism and how to solve - A school built by Baumann/ Prachenzky (1929/31) as case study (CS5) in 3encult (Michele Janetti) • Comparing solutions for retrofitting of a listed school building with internal insulation (Innendämmkongress Dresden, Michele Janetti) • Comparing Different Approaches for Moisture Transfer inside Constructions with Air Gaps insulation • Optimisation of daylight and artificial light in cultural heritage Hauptschule Hötting in Innsbruck, Austria (3encult Case Study 5) • Wissenswert Dezember 2013 • REHVA Journal issue 5/2013 p.24 (Rainer Pfluger) • PASIVNÍ DOMY 2013 (CZ) Publications • 3encult on BUILD UP - The European Portal For Energy Efficiency In Buildings Press review • Innsbruck informiert 18.10.2010 • Innsbruck informiert 6.5.2013

0.3 Detailed description

0.3.1 Urban Context and Local climate data

Urban Context	
	
Relation with neighbouring buildings	Isolated building
Quarter/town/surrounding	The schoolyard is orientated to the recreation area in the south alongside the river "Inn", View axes are targeting the landmarks as „Nordkette", visually from entrance and the classrooms in the northwest, „Patscherkofel" and the river „Inn" fromthe hall and main stairway. This strong interaction between buildings and surrounding landscape is very characteristic for early modern architecture in Tyrol.
Development plans	The building complex has both outstanding qualities as structural space and valuable details typical for its constructing-period and therefore was declared historical monument in 2008 following §2 DMSG.
Certificates/reports/regulations on energy efficiency	Building has high heating energy demand (about 123 kWh/(m²a) determined by PHPP)
Key figures as e.g. % of historic buildings, renovation rate	no file associated
Necessary data for PHPP calculation available: Monthly mean averages of temperatures and solar radiation?	yes

Local climate date	
Climate zone	III, 3

Climate area	Central European continental climate, Dfb (Köppen climate)
Degree days	3393 [(d K)/a]
Coordinates:	Lat N 44,267° - Long E 11,4°
Altitude	574 m.s.l.
Average wind speed	1,80 m/s
Prevailing wind direction	East/West

Building plan showing the north

Winter climate data		Summer climate data	
Winter design temperature	-8,2°C (cloudless, cold) and -1,4°C (cloudy, mild-cold)	Temperature: dry/wet bulb	21,3°C
RH max (Nov.-Dec.)	79%	RH	71,7%
Heating day per year	205 days	Daily temperature range	10°C

Available data for the project	Central Institute for Meteorology and Geodynamics
Reference statistic data from “common database” (e.g. Meteonorm)	Innsbruck Airport weather station

Data measured from local weather station	yes

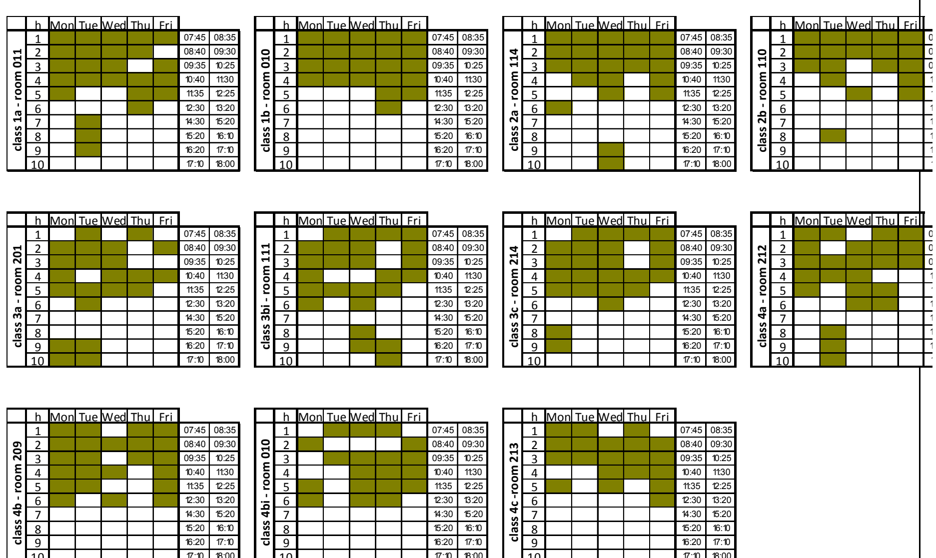
0.3.2 Report on history of the building

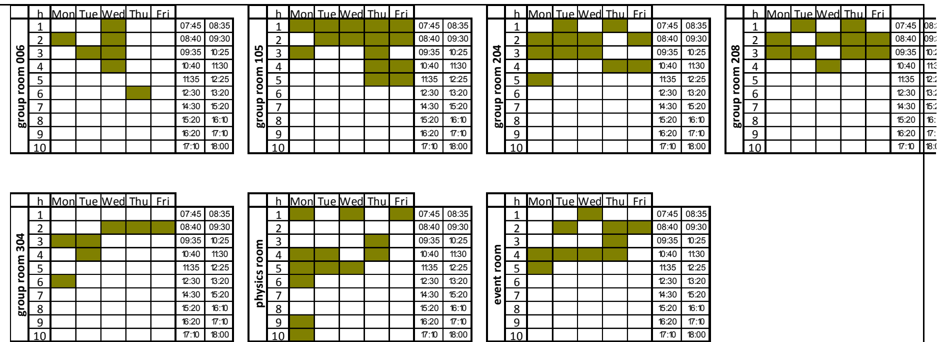
History of the building	
Use of building over time	In 1928 the municipalities of Hötting and Innsbruck announced an architectural competition for the planned new school building. The architects Franz Baumann and Theodor Prachensky succeeded with their project, strongly influenced by the architecture of Peter Behrens and Bauhaus. It has always been used as public school.
Other comments	At the moment an additional staircase is added in the south east.

0.3.3 Building consistency

Building consistency	
Description state of the building	Within the year's most parts of the genuine interior had been exchanged, only the built in elements still exist and are intended to be restored. The original colours and flooring materials (linoleum) were detected and are intended to be recovered. One main objective within the discussions between owner, architect and authorities of cultural heritage is the vision of the restored school building, the balance between restoration and adaption to the necessary demands of an up-to-date school preserving the specific atmosphere and characteristics of a building of the 30ties.
Description construction method	For the load-bearing part of the external walls three different material are used: · industrial produced extended brickwork: 58% of the external walls are made of brickwork with a thickness of 60cm in the lower, more loaded floors to 45 cm in the upper, less loaded floors. · rammed concrete: 42% of external walls are made of rammed concrete with a thickness of 45 up to 75 cm to bear bigger loads at the staircases, in the ground floor or in the basement. · armored concrete: less than 1% of the external walls are made of armored concrete to solve special static issues, for example the wall over the main entrance. These parts have a thickness of 60 cm.
Description shape	Elongated building
Description of facades and roof	Please see detailed report "Analysis of architectural elements" located in Associated documents, placed on the left side.
Number of floors above ground	Please see detailed report "Analysis of architectural elements" located in Associated documents, placed on the left side.
Number of basement floors	1
Covered area	1595
Numbers of rooms	84
Gross area	5778 m2
Net area	4524 m2
Heated surface	4524 m2

Surface cooled	0 m2
Heated volume	14982 m3
Other comments	BMS of CS5: - Lighting and shading has BMS (computer located at school) - Ventilation is self-controlled by motion and time schedule (in the future maybe will have BMS) - No more BMS so far in CS5 - In the future the lighting and shading will be extended to the entire building, then would be considered the use of BMS also for other HVAC (Ventilation, Hot water production, PV, Heating)

Occupancy rate (number of inhabitants/users)	20 pupils (10-14 years old) and 1 teacher per class room
Occupancy time (h/week, d/month)	Besides the weekly schedules a total number of about 74 days of holiday and additional feast days is assumed without occupation. Including the weekends, the school is unoccupied throughout 178 days of the year.  **Occupation schedule of the class rooms**



Occupation time schedules of the groop rooms, physics room and event room

Building Services (as- is-state)

Heating system

Lessons learnt about the decisions on appropriate heating and cooling systems for historic buildings are similar and sometimes correlated to the ventilation system. Repeatedly it strongly depends on the future use of the building and the demands in terms of temperature and comfort.

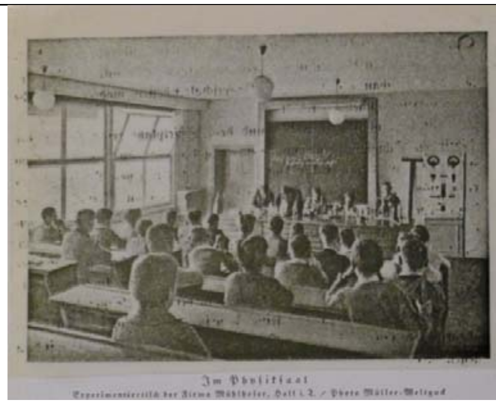
Moreover, the size and type of the applied system depends on the new heating and cooling loads after the interventions are performed. All reductions of heat losses by enhancement of the insulation of the building envelope, improvement of its airtightness and installation of any heat recovery systems will minimize the heat load and consequently reduce the size of the required heating and distribution system. If the heat emitting surface remains the same (as in case of the historic radiators in the class rooms of CS 5, which are part of the original architectural design), at least the supply temperature can be reduced significantly.

The treatment of the heat distribution system in case of a central heating depends very much on the location of the insulation layer with respect to the heating pipework. The most of the tubes are placed originally within the wall. This is no problem if the external insulation is applied. If an internal insulation layer is to be installed, the tubes can`t remain as they are due to the danger of frost. New internal insulated ducts have to be mounted, or (if possible) integrated in the insulation layer. The latter solution is an expensive solution with problems of thermal bridging and penetration of the airtight layer (internal plaster).

CS 5, Original radiator with new pipes inside the thermal envelope, Source: [UIBK, 2013]

Plant room	At the school there are 2 main plant rooms, one is situated in the attic in the third floor and the other one is located in the basement. In the attic plant room the gas boiler which supplies the school and the public swimming pool nearby is installed. In the second plant room in the basement the distribution for the heating system is located including all components such as pressure compensation container (see associated documents, photographs/images, plant room basement). Furthermore the installations to produce, store and distribute the drinking hot water are installed in this room.
Electrical System	In general the original electric system, which was installed at the first construction, still exists. Only in some parts the system was changed for example the artificial light installations in the floors. A few electrical installations such as the electrical control of the renewed heating supply and installations of computer working places and internet wires were added.
Ventilation System	Most of the historic buildings originally where ventilated by window venting in principal of cross ventilation and stack ventilation. During winter time the ventilation in historic building worked similar as in case of exhaust air systems today. The negative pressure inside the building was created by the stove heating in the same way as it is performed by a fan. The outdoor air passed inside through leakages in the building envelope. In summer time, stack ventilation during night time helps to keep the building cool. The following questions have to be answered considering the interventions in terms of ventilation: • What was the original use of the building (humidity sources, odor emission etc.)? • Are there any damages by moisture (mold growth, wood rot, wood worms etc.)? • What was the original way of ventilation (openings in the building envelope in terms of openable windows, leakages within the building envelope and internal flow paths such as ventilation shafts etc.)? • What is the intention for future use of the building (humidity sources, odor emission etc.)? • What about the airtightness of the building envelope after the interventions? • Which type of heating system will be applied in future? Problems with mold growth mostly will arise, if the building envelope becomes airtight and the stove heating system is replaced by a central heating system. Humidity from indoor sources is not vented out effectively if the users do not open the windows regularly. Mechanical ventilation may help to solve humidity problems even under changed conditions of use and can fulfil todays comfort demands. If it is possible to apply heat recovery ventilation, the comfort as well as energy efficiency is even improved. The section about ventilation in this handbook describes several new ideas and developments especially for integration in historic buildings, however there is no general solution or way how to ventilate in a most conservation compatible way. If possible the best way is to avoid any ducts (e.g. by cascade ventilation or active overflow, see CS 5 and section about ventilation)
Cooling System	At the school no cooling devices are installed.
Renewable Energy	A PV-test setup with reversible mounting system is placed on the original roof of the school building. In collaboration with the case study team (architect, local heritage authority, heritage authority Vienna (BD) and the building owner) the possibility for realization of a real installation (full size) will be investigated. A

	monitoring of module temperatures as well as solar irradiation and module power simultaneously will be performed to evaluate the efficiency under real conditions (problem of overheating, dependent on gap width). Moreover the glare problem will be evaluated and tested. An anti-reflective surface was chosen, however a rest reflection will remain. The effect should be minimized, both for design and conservation reasons as well as to avoid glare for the pilots of aircrafts approaching for landing at the airport nearby. The evaluations and results are an important basis for decisions for the upcoming EU-project SINFONIA. Within the BEST sheets, a minimum PV installation for most of the buildings was promised. The test setup will deliver important information for the decisions where and how to install PV on listed buildings, as due to the Austrian regulations from BDA it is restricted. The technical data of the test setup are as follows: 20 Modules 250Wp each (5kWp total peak power) mounted in a reversible way by special standing seam mounting  Standing seam mounting holder TIGO monitoring and control/security system (module mpp-tracking, module temperature measurement, irradiation measurement at module level)
Artificial Lighting	Energy-saving light sources open a wide range of opportunities besides the saving potentials of electronic ballasts and control. New LED-technology, close to the market breakthrough, gives also the possibility of light temperature control. As a prototype, this technology with daylight adaptive light temperature control was tested in one classroom of CS 5. From cultural heritage authority there was no negative assessment, as the new technology only substitute the fluorescent tube technology, which was not the original type of artificial light either, it was the incandescent light bulb (see Figure: Original incandescent light bulb).

	   **Original incandescent light bulb [Festschrift; UIBK, 2012]** Besides the advantages of energy efficiency and light quality (color temperature), the LED technology gives new impetus to some further improvements leading to a high quality artificial light in museums and historic buildings for illumination of paintings and artefacts. Solutions able to significantly reduce the electricity consumption due to artificial lighting have been studied, i.e. working with power regulation with respect to the effective visitors present in the room.
Use of Daylight	All the corridors and the entrance hall of the building are orientated to a large glazing area to guarantee beside architectural issues that the daylight can pass into the building as much as possible. Also the classrooms have big windows, in relation to the building style of the time of the first erection of the building, to use as much daylight as possible. But the actually income of daylight is strongly reduced by all the frames and muntins and the original sunscreen which is sometimes necessary to avoid glare.
DHW production	The drinking hot water is produced with the warm water from the gas boiler. The storage tank is situated in the plant room in the basement. Additionally an electric heater is installed at the storage tank. From the storage tank three main ducts for DHW are leading to the kitchen, the room of the student´s fraternity and the cloakrooms of the gym with its showers. Other rooms with DHW as the craft rooms, the doctor room and the tea kitchen are equipped with a decentralized boiler supplied with electricity.

Chimney/ducts	Originally three chimneys, one in the middle of the west part of the building and two beside the main corridor of the east part, exists. Later with the new gas boiler system located in the attic one huge chimney for that boiler was added.
Others	During the measurements was find out that the reverberation time is very long. This phenomena causes lack of understand ability during speaking.

0.3.4 Building Energy consumption

Building Energy consumption			
Electricity	**Years**	**Consumption (kWh)**	**Cost (€) (average cost €/kWh)**
	2008		736.900 (0,123)
	2009		
	2010	27069*	
Gas	**Years**	**Consumption (mc)**	**Cost (€) (average cost €/mc)**
	2008	858197600	
	2009	828680500	
	2010	881002200	

* excluding the energy for warming a public swimming pool

0.4 Constraint condition and protection

Insulation and building tightness: *Exterior Insulation is inacceptable in any case. In some cases interior insulation is acceptable to make an insulating inner wall if there are no panels or other architectural details. This intervention must be removable without damaging the genuine structure.*

Windows and shading: *The genuine windows should be preserved. Due to the already done interventions on the old windows, the effort to repair/restore the old windows is much higher than to rebuild them, so reconstructing them could be a solution in this special situation (but is not a general advice!). The double glazing for the inner wings is acceptable. The new daylight guiding venetian blinds mounted within the wings are acceptable during the time of measurements.* The intervention can't be assessed at the time for the whole building. It can be considered, if it doesn't disturb the buildings main heritage value.

Heating and cooling: The genuine tube-radiators are essential elements of the interior design and must be preserved.

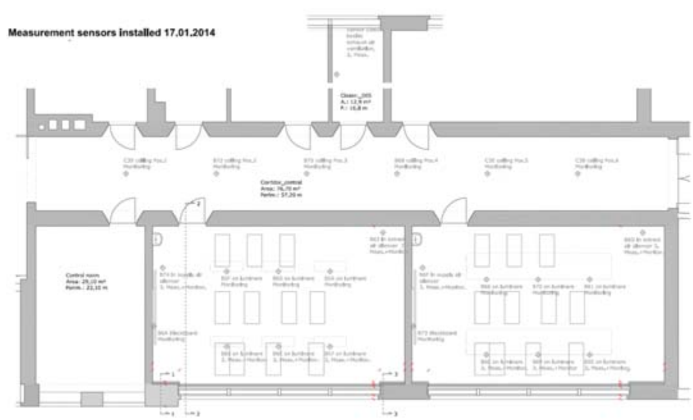
Ventilation: Window is designed with the intention to be opened. An additional ventilation system with the least possible impact on the genuine structure (using f. ex. secondary rooms for distribution) is conceivable but has to respect the high quality of the genuine interior architecture. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.

Electricity/ Lighting: The intervention can't be assessed at the time. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.

Acoustics: The intervention can't be assessed at the time. It can be considered, if it doesn't disturb the buildings main heritage value.

0.5 Selected area of intervention

0.5.1 Functional area: Two test classrooms

Functional area consistency	
Description	Test rooms: Classrooms 1 and 2
Number of rooms	2
Heritage aspects	All classrooms are opening to the outside with horizontal lines of windows, bringing light and air into the classrooms. Quite new at this time were also the central aisles with classrooms on both sides.
Balance boundary	
Treated floor area according to balance boundary	2 x 65m2
Height interpolated average net (m):	3,38 m
Surface area (Gross/Net) heated (mq):	130m2
Volume (gross/net) heated (mc):	440 m3

Opening to the public (from/to; hours /day; temperature set-up):	-
Hours of working (from/to, hours/ day; temperature set-up):	Room temperature was adjusted be thermo head. The observed occupation hours are documented in section 0.3.3.
Hours of air conditioning (from/to; hours/day; temperature set-up)	AFTER INTERVENTION : 7-13 is ventilation constantly ON. Out of this time is ventilation controlled by demand (motion sensor)
Comments	Central access

1 Report on status pre-intervention

The first step within the work on the case study was an intensive analysis of the actual status of the building, in terms of preservation and from architectural as well as from building physics point of view. Moreover, the thermal comfort within the classrooms was measured according to ISO 7730 as well as the indoor air quality by evaluation of the CO_2-concentration.

1.1 Analysis of architectural elements

In 1928 the municipalities of Hötting and Innsbruck announced an architectural competition for the planned new school building. The architects Franz Baumann and Theodor Prachensky succeeded with their project, strongly influenced by the architecture of Peter Behrens and Bauhaus.

The building complex has both outstanding qualities as structural space and valuable details typical for its constructing-period and therefore was declared historical monument in 2008 following §2 DMSG.

The genuine design concept follows strictly the principles of functional architecture. Well proportioned, mainly horizontal situated volumes in the northwest of the land plot are escalating in a slightly offset tower in the northwest edge: a landmark visible from the street, signing the entrance and marking the most important section of the building. This part locates the hall and main-stairway, the administration in the first floor and the biggest classrooms used for major school events. The architects intended to enclose the school yard with two nearly rectangular wings on the northwest and northeast and a smaller, one storey building in the southwest locating the gym. The schoolyard is orientated to the recreation area in the south alongside the river “Inn”, View axes are targeting the landmarks as „Nordkette“, visually from entrance and the classrooms in the northwest, „Patscherkofel“ and the river „Inn“ from the hall and main stairway. This strong interaction between buildings and surrounding landscape is very characteristic for early modern architecture in Tyrol.

All classrooms are opening to the outside with horizontal lines of windows, bringing light and air into the classrooms. Quite new at this time were also the central aisles with classrooms on both sides.

The architecture is determined by a very stringent and straight design, the original colours and surfaces (exterior: pedestal body and gym walls in bus-hammered concrete, walls and ceiling in light grey, wooden furniture, white painted windows): all creating a reluctant, slightly cool but relaxing and open atmosphere for pupils and teachers.

Due to the economic crisis in 1928 only the main wing on the northwest side, following the „Fürstenweg“, and the gym in the southwest were realised between 1929 and 1932. After the annexation of Austria into Nazi Germany in March 1938, air-raid shelters had been constructed in the school-yard.

In the years following WW2 the school was enlarged on the eastside, the originally planned second wing had never been built. Up to the 80thies only very few interventions had been done and therefore a lot of the original structure could be preserved. Not in genuine condition are most of the windows (upper wings now opening to the interior side of the room), the heating central (which has been moved from the ground floor to the roof), the lighting, the door handles, school furnishings (except the built in furniture) and the painting. Also some parts had to be installed because of new building regulations as emergency lighting, fire doors, a rescue stairway and an elevator.

Within 3Encult different interventions improving the energy efficiency of the building were discussed with the Austrian Authority for Cultural Heritage BDA, represented by Landeskonservator Hofrat Dipl.-Ing. Werner Jud, the IIG as owner of the building and the architect.
Since the opening in 1932 not only the methodologies in teaching but also the building codes and guidelines and convenience standards for school buildings have changed, the building therefore has to be adapted to fulfil these demands respecting the interests of cultural heritage.

- Improving of shading, lighting, acoustic, thermal comfort and air quality
- Integration of computer cabling and new technical equipment

Typical construction-flaws due to improper workmanship and a lack of knowledge and experience are causing damages within the construction, which have to be taken in consideration:

- Reinforced concrete: Insufficient covering of the reinforcement, insufficient crack reinforcement, no thermal separation causing severe thermal bridges,
- stone-wood-screeds screeds: magnesia-chlorides as binders are causing severe corrosion of the reinforcement within the floor slabs if the construction gets humid, also due to the lack of a separation layer between screed and bulk
- severe air-leakage of the thermal envelope due to uptight window-, façade-, roof- connection

Within the year's most parts of the genuine interior had been exchanged, only the built in elements still exist and are intended to be restored. The original colours and flooring materials (linoleum) were detected and are intended to be recovered.
One main objective within the discussions between owner, architect and authorities of cultural heritage is the vision of the restored school building, the balance between restoration and adaption to the necessary demands of an up-to-date school preserving the specific atmosphere and characteristics of a building of the 30ties.

Below a list of interventions tried out in the two demonstration classrooms:

Insulation and building tightness

Baseline situation: About 40% of all heat transmissions of the building are passing through the exterior walls. A remarkable improvement of the energetic building performance needs a reduction of the heat transition which can be managed with either interior or exterior insulation.
Authority (BDA):
Exterior Insulation is inacceptable in any case.
In some cases interior insulation is acceptable to make an insulating inner wall if there are no panels or other architectural details. This intervention must be removable without damaging the genuine structure.
Architect:
Facing the limited budget, existing/raising problems in this special case study with building physics (thermal bridges, condensation within the construction) and the risk of interior insulation, causing additional humidity into the support area of the floor slabs nearby the magnesia screeds, the architect prefers exterior insulation. He assumes that if done in a sensible way which does not change the proportions of the building, exterior insulation as a removable wear layer could be an option not only to solve the existing problems of thermal bridges and condensation within the construction but also to preserve the genuine construction from further damages and to keep the genuine heating distribution and radiators in place.

Windows and sun shading

Baseline situation: existing windows are only partly genuine, already damaged and generally in a bad state of repair. Existing load bearing steel columns within the window lines, unprotected against fire impact and also severe thermal bridges. Leakages caused by not airtight plaster/windows-connections. The original shading - a roller blind mounted within the two wing layers – is inefficient and damage-prone.
Authority (BDA):
The genuine windows should be preserved.

Due to the already done interventions on the old windows, the effort to repair/restore the old windows is much higher than to rebuild them, so reconstructing them could be a solution in this special situation (but is not a general advice!). The double glazing for the inner wings is acceptable.
The new daylight guiding venetian blinds mounted within the wings are acceptable during the time of measurements. The intervention can't be assessed at the time for the whole building. It can be considered, if it doesn't disturb the buildings main heritage value.

Architect:
Prefers an improved reconstruction of the old windows following the old drawings and in this way receiving a higher quality in a more cost efficient way. Attention has to be paid to the steel columns (I-girders) running vertically through the window lines. In accordance to the new building laws, they have to resist a fire impact of at least 90 minutes and have to be protected either by fire protecting coat or plasterboard.
In the eventuality of an exterior Insulation, the windows have to be shifted to the outside, keeping the proportions of the existing window embrasures.

Heating and cooling

Baseline situation: The measured heating demand, being about 25% higher than the calculated one, resulted mainly out of not adjustable room temperatures, caused by the enormous thermal mass (about 400-500 kg) of the radiators with a flow temperature of about 85 degrees Celsius. So in winter, room temperature was regulated by opening the windows. This caused very dry air and very uncomfortable conditions for pupils, having their seats near the window line. In summer especially on the west facades the solar gains are high, resulting in overheating.
The heating central is placed under the roof, providing not only the school but also the public swimming bath in the neighbourhood. Heat losses are high. It is intended to separate the swimming bath from the heating central and to construct a new heating central for both: the actually new built school SPZ in the south of the gym and the old school.
Authority:
The genuine tube-radiators are essential elements of the interior design and must be preserved.
Architect:
To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the existing problems with dry air and discomfort should be improved: the radiators, essential element for the genuine interior design must be optimised to fit to the demands of comfort. Within the thermal refurbishment the flow temperature should be lowered to a level, which allows a feasible integration of renewable energies. The thermal mass of the radiators should be reduced. Also the thermal mass of the floor slabs should be used as a thermal buffer to prevent expensive active cooling.

Ventilation

Baseline situation: insufficient natural ventilation through windows. Measurements have brought up, that even with leakages the indoor air quality during lessons is insufficient and mechanical ventilation necessary to fulfil the obliged value with a maximum of 1500 ppm CO_2.
Authority:
Window is designed with the intention to be opened. An additional ventilation system with the least possible impact on the genuine structure (using f. ex. secondary rooms for distribution) is conceivable but has to respect the high quality of the genuine interior architecture. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.
Architect/Scentist:
Architect: To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the existing problems with air quality should be improved.

Scientist: Proposes a cascade ventilation system, using the space of the old heating central under the roof, using the main stairway and the corridors, bringing in the fresh air, guiding/collecting the waste air through pipes situated in secondary rooms as wardrobes, washrooms, toilettes, up to the roof, using a heat exchanger to warm up the fresh air.

Electricity/Lighting

Baseline situation: existing electrical installation is not in accordance with technical standards and guidelines and not capable to fulfil the demands of new technical equipment and common IT solutions due to new methodologies in teaching. Insufficient lighting-conditions in the classrooms on two-third of the tables (measured values of about 150 Lumen, obligation for classrooms minimum of 300 lx)
Authority:
The intervention can't be assessed at the time. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.
Architect/Scentist:
Architect: To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the electrical installation has to fulfil the demands and has to be flexible enough to implement further possible needs.
Energy efficient solutions should be preferated.

Acoustics

Baseline situation: very long reverberation times, lack of understandability
Authority:
The intervention can't be assessed at the time. It can be considered, if it doesn't disturb the buildings main heritage value.
Architect:
Improving of understandability is absolutely necessary for an optimum setting for learning.

1.1.1 Thermal envelop

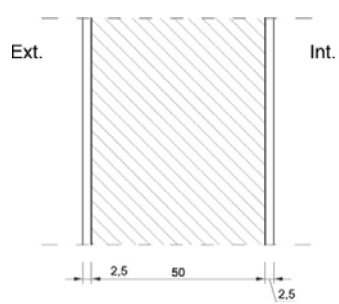
General description of Rainer Pfluger, Kai Längle, Michele Bianchi Janetti, Pavel Sevela, UIBK; Architect Gerald Gaigg
According to the status quo was the thermal envelope insufficient according to the nowadays standards of thermal comfort, thermal resistance and airtightness.
Heritage aspects
Insulation and building tightness: *Exterior Insulation is inacceptable in any case. In some cases interior insulation is acceptable to make an insulating inner wall if there are no panels or other architectural details. This intervention must be removable without damaging the genuine structure.* **Windows and shading:** *The genuine windows should be preserved. Due to the already done interventions on the old windows, the effort to repair/restore the old windows is much higher than to rebuild them, so reconstructing them could be a solution in this special situation (but is not a general advice!). The double glazing for the inner wings is acceptable. The new daylight guiding venetian blinds mounted within the wings are acceptable during the time of measurements.* The intervention can't be assessed at the time for the whole building. It can be considered, if it doesn't disturb the buildings main heritage value. **Acoustics:** The intervention can't be assessed at the time. It can be considered, if it doesn't disturb the buildings main heritage value.

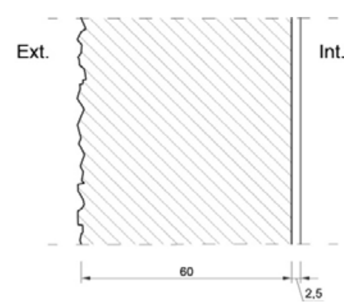
Facades & external walls:

For the load-bearing part of the external walls three different material are used (see Figure above):

• industrial produced extended brickwork (red): 58% of the external walls are made of brickwork with a thickness of 60 cm in the lower, more loaded floors to 45 cm in the upper, less loaded floors (see the left Figure below).

• rammed concrete (green): 42% of external walls are made of rammed concrete with a thickness of 45 up to 75 cm to bear bigger loads at the staircases, in the ground floor or in the basement (see the right Figure below).





• armored concrete (blue): less than 1% of the external walls are made of armored concrete to solve special static issues, for example the wall over the main entrance. These parts have a thickness of 60 cm.

All the external walls of the ground floor and the upper floors are plastered in- and outside with a layer of 2-3 cm of lime-cement-plaster. The external walls of the wing of the gym and most parts of the basement walls are plastered inside with lime-cement-plaster too. At the outside surface of these walls is no additional plaster. The rammed concrete was while drying treated by hand to get a structured surface. This surface is so called “Stucko” (see the Figures below)

At the moment no technical data of materials are measured. For the calculation in the PHPP we presume values of the thermal conductivity based on values of materials from that time. There is no membrane applied in the external wall.

1.1.2 Rooms and room units

1.2 Structural analysis and assessment of moisture

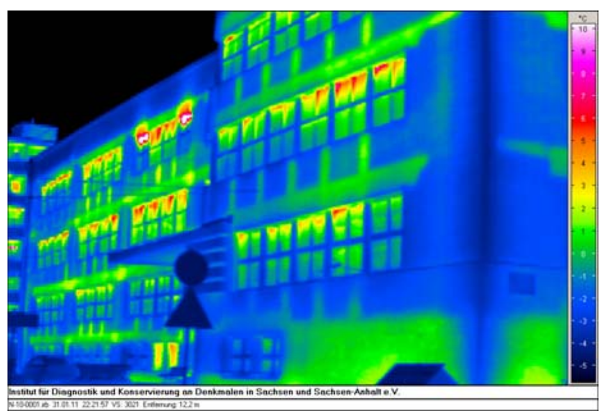
Blower door measurement

A blower-door test was performed in order to quantify the overall air leakage rate as well as to detect the most important leakages. The result of pressurization test was an n_{50}-value (air change rate at 50 Pa) of 4.8 1/h (+/- 20%) for the school building and 2.8 1/h (+/- 9%) for the gym. In order to see the influence of leakages at the original windows, the blower-door was mounted in a classroom, the result was n50= 5.8 1/h (+/- 6%).

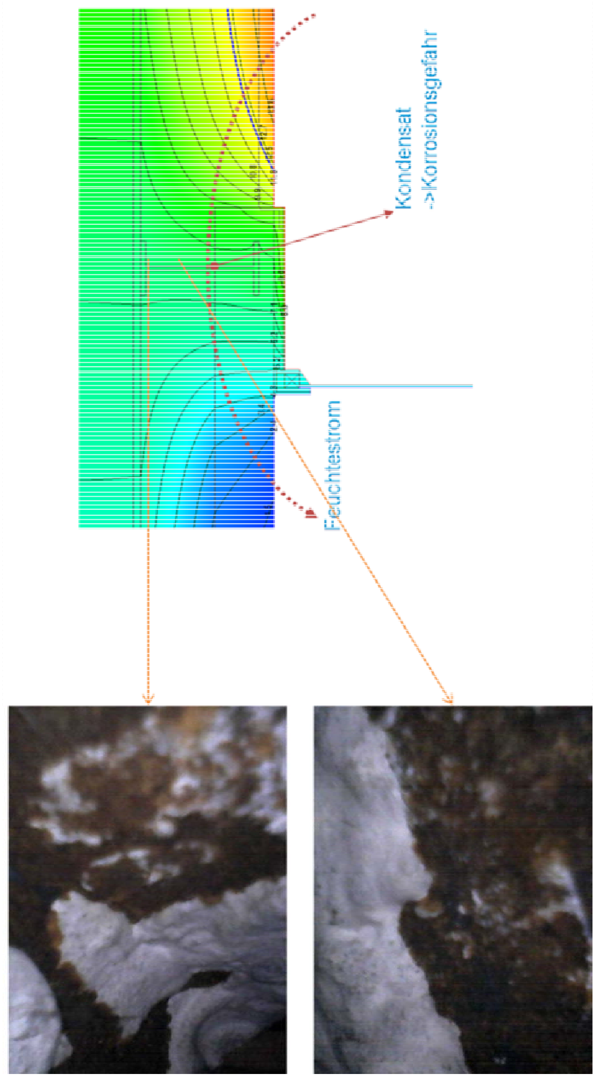
About 40% of all heat transmissions of the building are passing through the exterior walls.

The energy balance calculations by PHPP as well as measurements and analysis on building details provided a good overview on the mayor energy consumption

IRT-diagnosis helped to find energy efficient solutions with high priority of conservation-compatibility for all of the interventions (see also [Franzen 2011]).



View from West; Source: Christoph Franzen (Institut für Diagnostik und Konservierung an Denkmalen in Sachsen u. Sachsenanhalt), The IR-images where taken during nighttime (31.01.2011) at an ambient temperature of around –5°C. All rooms where heated to an indoor air temperature of around 25 °C.



Detain of Roof: steel-stone ceiling with concrete topping,
Screed / Flooring: stone wood flooring with coved training (Magnesite coating)
Floor surfac in class rooms: corklinoleum.

Report written by Assistant Professor Gerd Fritsche
- Ceiling structure at the end of the service life
- Immediate action required
- Carbonation progressed, no corrosion protection!
- Check-ups every 10 years necessary
- Renovation in the former coal cellar urgently required

Steinholzböden: Problematik „ Magnesiumoxychlorid “

1.3 Environmental monitoring

To simplify the measurements one classroom was chosen, which represent the other frequently occupied room in dimensions, artificial light installations, orientation and so on. This standard classroom in the ground floor was analysed in different aspects like light situation, thermal comfort and indoor air quality.

The acoustic (reverberation time) and visual comfort (daylight coefficient and artificial light distribution) was measured as well. Figure below shows a luminance measurement of the class room before intervention with poor artificial lighting (on two-third of the tables only 150 lux were measured, see also [Pfluger 2011]).

Luminance measurement in the classroom with artificial light

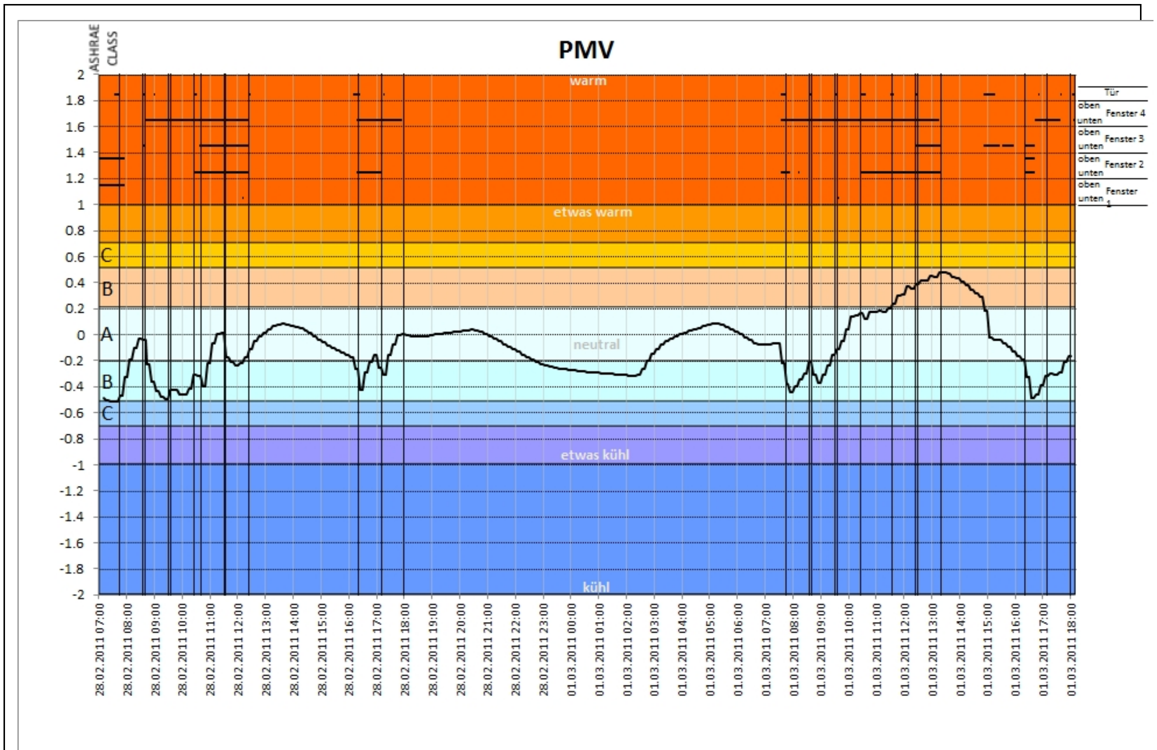
Thermal comfort

The thermal comfort is a human sensation, which is influenced by external influences from the environment. Comfort is a combination of physiological, psychological, sociological and aesthetic influences. To measure the manual ventilation behaviour open/close loggers with reed contacts were mounted at the windows.

In addition to the series of measurements you need other input parameters such as clothing factor, activity level and mechanical power to work.

The PMV-value is the average estimate (from 3 hot cold to -3) of the indoor climate.

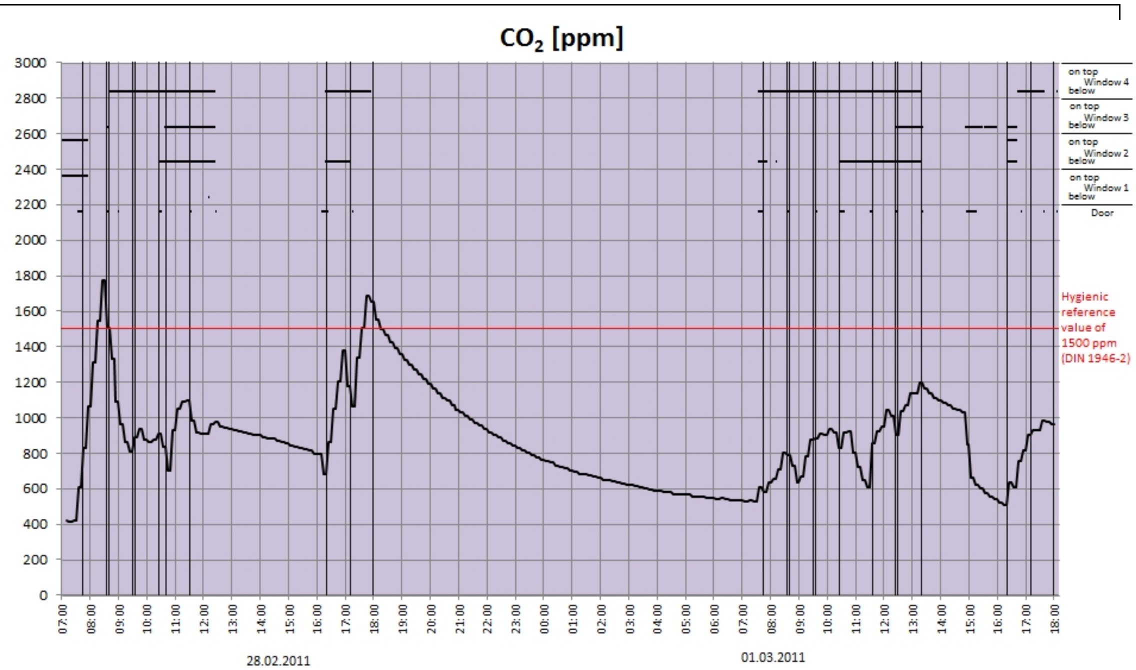
Sensors for assessment of thermal comfort and for CO2 measurement (assessment of air quality).



Thermal comfort evaluation

Indoor air quality

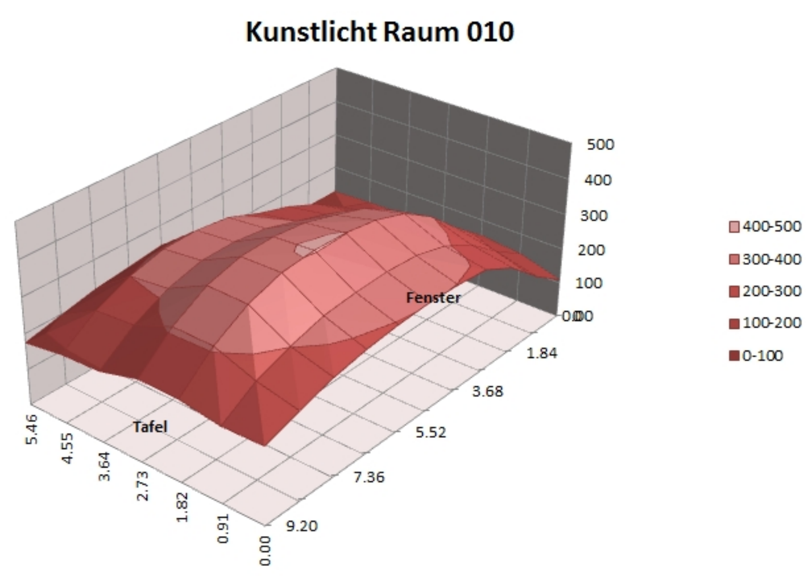
The CO2 concentration is a good parameter to qualify the air quality inside rooms. It was measured at the same altitude (1m above floor level) as the values for the PMV-calculation. The occupancy of the rooms is important for both measurements: indoor air quality and thermal comfort.



Time-evolution of CO_2 concentration

Artificial light

Percentage of the artificial light: On / off logger are mounted on the fluorescent lamp. It can be determined how often, how long and at what times they are used. This provides insight in the general use of the lamps and hence the power consumption.



Internal illuminance [lx]

Artificial light measurement

Daylight

The daylight factor is a measure of the day light feed into rooms. It consists of the ratio of illuminance E_{int} at a point in the interior to the outside illumination E_{ext} of an unobstructed unshaded

point. The daylight factor indicates what percentage of the external illumination passes through openings into a room. The daylight factor is a geometrical parameter that depends on:

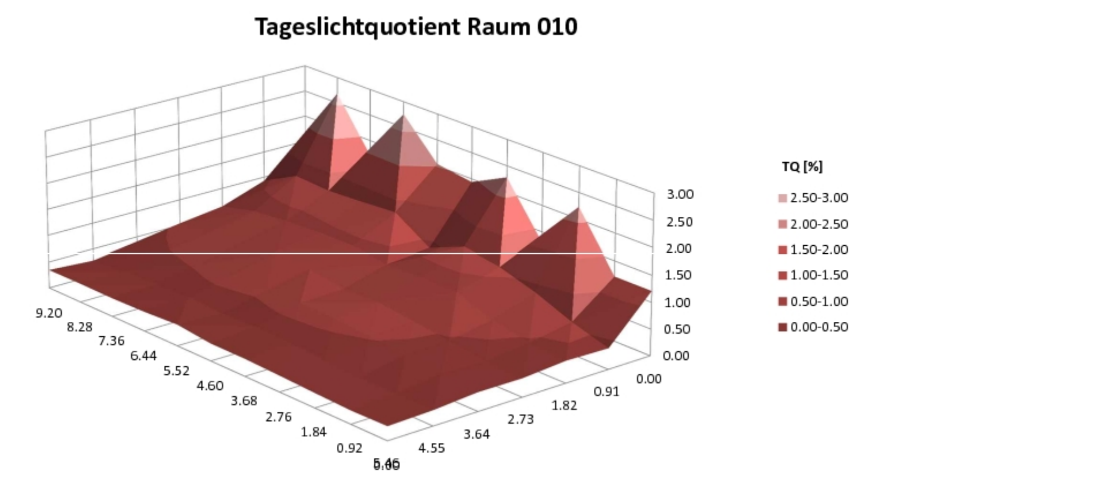
• Room proportions (height, length, width);

• Skylight geometry (area, location, context and sprouts, shaft shape)

• Glazing material (transmittance, pollution) and the

• Reflectance of room surfaces and shafts

Illuminance sensor internal (left) external (right)



Daylight coefficient (internal illuminance/external illuminance [%])

1.4 Results derived from the application of PHPP

This issue is very well documented in Delivery 7.5 Evaluation of the monitoring and PHPP data, chapter 2.3.1.

Within the 3ENCULT project, the whole building of case study 5 the Höttinger School was studied in detail and the PHPP was fed with all parameters. Hence, it is possible to calculate the theoretical annual heating demand of the school before and after interventions and execute the comparison, which is the task in this report, of the annual heating demand before intervention.

As mentioned before, it is important to take in account that the installed heat meter measures the real energy consumption of the school without taking in account the losses of the ducts between the boiler and the distribution system. However, these losses cannot be neglected in PHPP calculation because it is true and significant part of the building services solution in term of energy demand. Therefore, it was necessary in the first step to calculate the heat loses of that riser duct in PHPP. Parameters such as the length or the flow temperature of the riser ducts were considered for the annual losses of the riser duct calculation (see equation below).

$Q_{HL} = L_H * q_{*HL} * \eta_G$

Q_{HL}… Annual losses
L_H… Length of distribution pipes
q_{*HL}… Annual heat emission per meter of plumbing
η_G… Possible utilization factor of released heat

In our case, the losses of the riser ducts function like an additional heat consumer according to the energy balance, because they are inside the building thermal envelope. In order to compare the measured and the calculated data it was necessary to decrease the annual heating demand calculated in PHPP by these losses. To demonstrate clearly these considerations, the next equation shows the connection between the calculated and measured energy balances in this specific case:

Measured Data (IIG) = Annual heat Demand (PHPP) – (Losses of riser ducts for supply /Treated floor area)

In the Table below the measured annual consumption values were divided by the treated floor area to create a comparable value (see table 2, 4th column). Further, the calculated annual heating demand was reduced by the annual losses of the riser ducts. The resulting calculated and measured values, which are comparable, are highlighted in the 4th and the last column.

Table 1: Calculation of the for the comparison needed values

1 time period	2 measured heating consumption [kWh/a]	3 treated floor area (PHPP) [m²]	4 measured heating consumption [kWh/(m²a)]	5 calculated heat demand [kWh/(m²a)]	6 losses of riser ducts [kWh]	7 losses of riser ducts [kWh/m²]	8 calculated heating consumption minus riser ducts losses [kWh/(m²a)]
2005	559030	4089.86	**136.68**	129.34	13519.97	3.31	**126.03**
2006	471290	4089.86	**115.23**	129.34	13519.97	3.31	**126.03**
2007	427400	4089.86	**104.50**	129.34	13519.97	3.31	**126.03**
2008	474600	4089.86	**116.04**	129.34	13519.97	3.31	**126.03**
2009	458990	4089.86	**112.22**	129.34	13519.97	3.31	**126.03**
2010	487450	4089.86	**119.18**	129.34	13519.97	3.31	**126.03**
2011	683849	4090.86	**167.16**	129.34	13519.97	3.31	**126.03**

In the diagram below the measured annual heating consumption and the comparable values calculated in PHPP are presented.

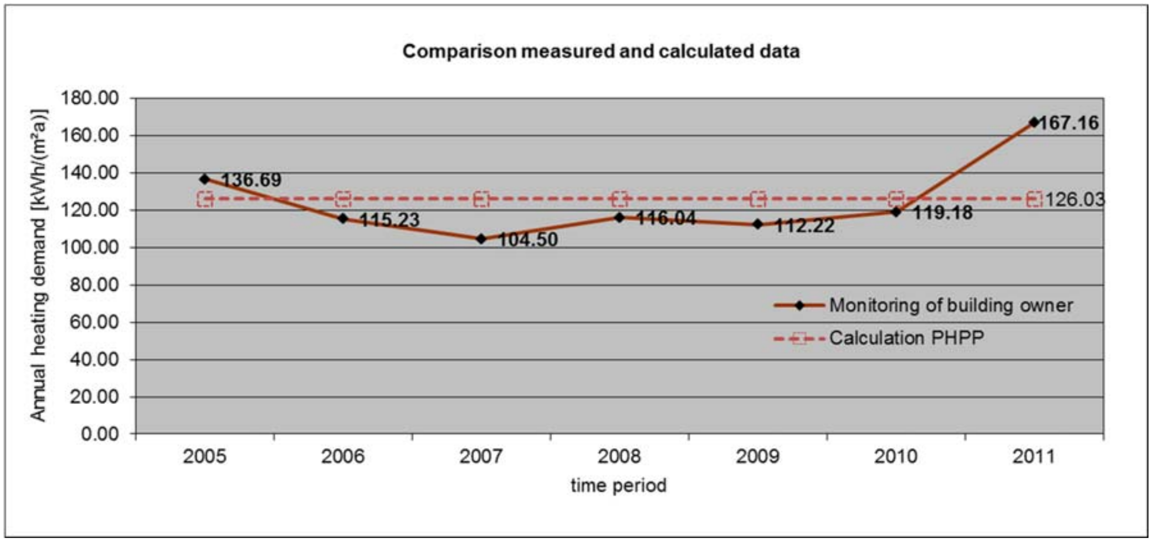
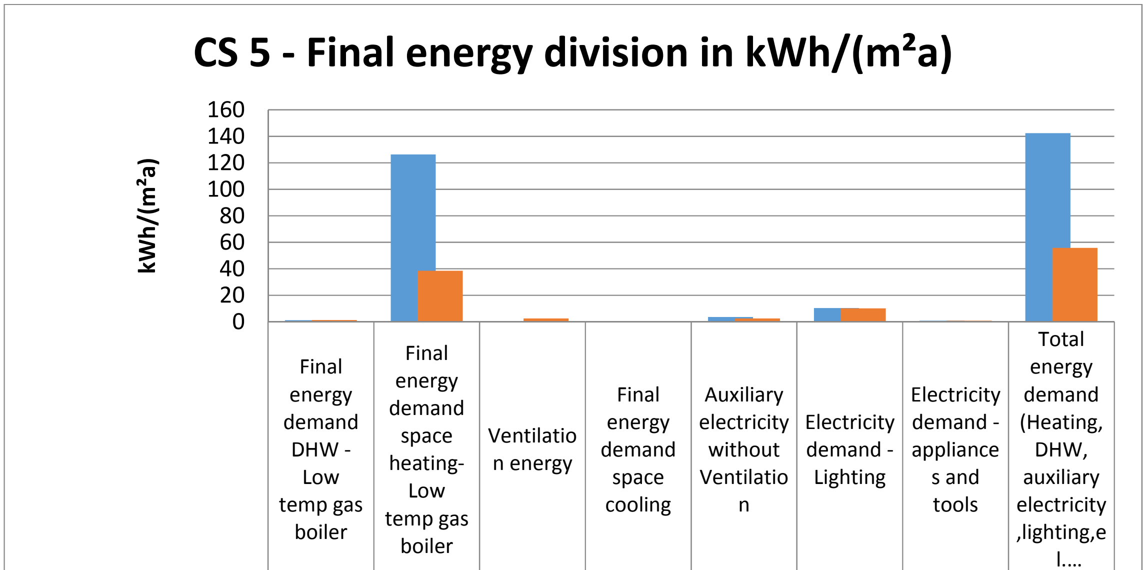


Diagram with the measured and calculated energy balances in the period from 2005 to 2011

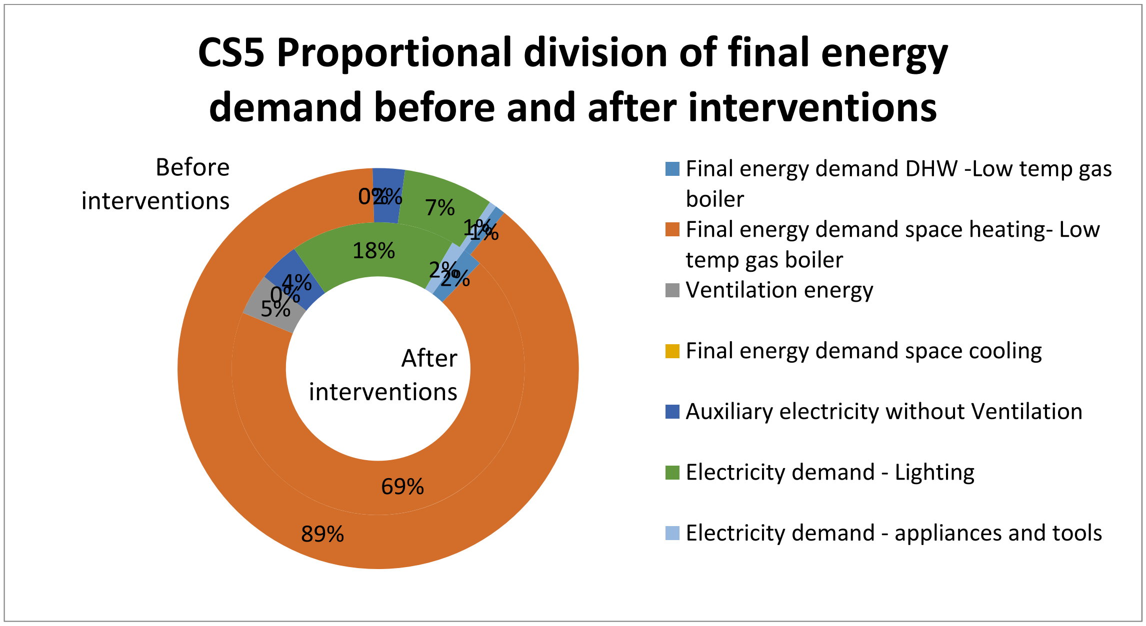
In the diagram is clearly visible, that the values of the measured energy balance of the last seven years commute around the annual heating demand, which was calculated with the PHPP. Depending on the climatic conditions of the different years the values of the energy balance is only in average 10% below or above the calculated annual heating demand. Only the measured value of year 2011 is 32% above the calculated level. This higher consumption may result from the extreme cold winter in 2011. But the difference between the mean value of all the monitoring data between 2005 and 2011 and the calculated data resulted with less than 2 kWh/ (m²a) difference, what can be considered as very precise. Hence the PHPP model was considered as a verified for further research of refurbishment variations and the PHPP tool itself has proved its applicability also to historic buildings.



	Final energy demand DHW - Low temp gas boiler	Final energy demand space heating- Low temp gas boiler	Ventilatio n energy	Final energy demand space cooling	Auxiliary electricity without Ventilatio n	Electricity demand - Lighting	Electricity demand - appliance s and tools	Total energy demand (Heating, DHW, auxiliary electricity ,lighting,e l....
Before interventions	1,175	126,365	0,000	0,000	3,688	10,343	0,849	142,420
After interventions	1,236	38,545	2,545	0,000	2,497	10,163	0,849	55,835

CS 5 - Final energy division

On the **Fehler! Verweisquelle konnte nicht gefunden werden.**above and below can be seen closed division of energy consumptions outlined by PHPP simulation tool. The variation after intervention contains all proposed energy efficient solutions.



CS5 Proportional division of final energy demand before and after interventions

The energy demand after interventions is higher because the "Marginal Utilisability of Additional Heat Gains" from heating system are smaller.

1.5 Overall rating

High heating energy demand (about 130 kWh/(m²a) and severe overheating problems during summer period due to large up-shaded glazing areas. This some of the classrooms cannot be used during summer season. Air quality problems and low thermal comfort (draft risk and low surface temperatures in winter) are further problems, which have to be solved.

Building services:

Electrical system / electric installations

In general the original electric system, which was installed at the first construction, still exists. Only in some parts the system was changed for example the artificial light installations in the floors. A few electrical installations such as the electrical control of the renewed heating supply and installations of computer working places and internet wires were added.

Ventilation system

In general no ventilation system was installed in the school. Only some rooms with a special use are equipped with an extract air ventilation system, such as the kitchen and the craft rooms in the basement. All the other rooms are ventilated manually, which cases high energy losses in wintertime.

Heating system

Manifold radiators in classrooms **Lamellas radiators in classrooms**

Heating system of the building: The original radiators in the classrooms and corridors consist of a manifold of tubes. In the annex part of the building from 1950 radiators with lamellas are mounted. Some radiators in the old part of the building also were already changed for example in the dining room.

The central heating and radiators has an origin in 1930´s, Heat plant is running on gas and supply heat beside the school also the public swimming pool "Höttinger Au".

The boiler is situated in the cold attic in the third floor and the distribution for the heating system including all components such as pressure compensation container is located in the basement (see Figures below). Furthermore the installations to produce, store and distribute the drinking hot water are installed in this room.

Distribution system located in the basement

Cooling system

At the school no cooling devices are installed.

DHW production

The drinking hot water is produced with the warm water from the gas boiler. The storage tank is situated in the plant room in the basement. Additionally an electric heater is installed at the storage tank. From the storage tank three main ducts for DHW are leading to the kitchen, the room of the student´s fraternity and the cloakrooms of the gym with its showers. Other rooms with DHW as the craft rooms, the doctor room and the tea kitchen are equipped with a decentralized boiler supplied with electricity.

Artificial lighting

Most of the classrooms are equipped with four luminaires with two fluorescent tubes each. No additional luminaires to light the blackboard are installed. In the corridors, conference rooms, library and directors office newer and more efficient lighting system are installed.

Annual Heating demand:

The heating supply of the school was changed a few years ago. The new gas boiler to provide the heating demand is situated at the third floor in the cold attic. It is installed there because of safety reasons and due the fact that the building was not considered at the first erection for installation of such a huge boiler. The new gas boiler supplies the energy demand of the school and of the public swimming pool, located nearby opposite of the street in west direction. From the boiler the warm water is led over a riser duct to the distribution system in the plant room in the basement. After the distribution dominant amount of the warm water is led along the inner side of the external wall to the northwest corner of the building and then below the street to the swimming pool. About 76% of the in the school produced energy is provided to the swimming pool (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). All the ducts are well insulated but although a lot of energy gets lost. Especially the losses of the riser ducts between the boiler located in cold attic and the distribution system in the basement are not taken into account in the measured energy balance, because the heat meters are mounted at the distribution system downstairs. This fact is important for the comparison of the measured and calculated energy consumption values (see below).

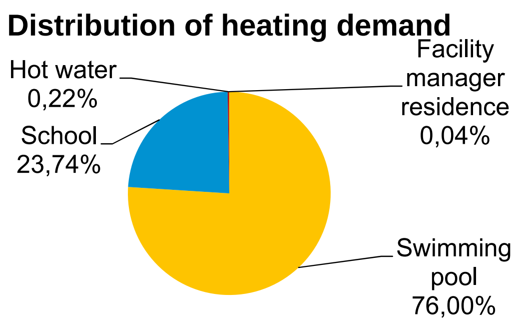


Diagram of the heating demand distribution

Measured energy balance:

To distinguish between heating costs of the school and of the swimming pool the building owner installed heat meters at the distribution system located in the basement (see figure below). The first heat meter is counting the heat consumption for the heating system of the school building. The second one is measuring the consumption for the supply of the drinking hot water and the third one is counting the energy supplied to the swimming pool. Hence, the consumptions of the various systems are clearly recognizable.

Installed heat meters located in the plant room

For further analysis of the school building the owner (IIG) made available the consumption data measured during last 7 years (see table below). Thus, the measured energy balance of the school since 2005 to 2011 is well defined.

Table 2: Measured data from building owner

time period	Heating consumption of school [kWh/a]	Energy consumption of DHW at school [kWh/a]
2005	559030	5310
2006	471290	4330
2007	427400	4140
2008	474600	4840
2009	458990	3960
2010	487450	4730
2011	683849	3720

2 Design

2.1 Intervention needs

At the refurbishment works at the school within the 3ENCULT-Project two classrooms so called prototype classrooms were redeveloped to demonstrate the possible energy efficient solutions and to get important experiences for the renovation of the whole school. Because only parts of the building were refurbished so far, there is no clear boundary between the renovated part and the old part. The refurbished prototype classrooms are located in the middle of an arrangement of rooms and the central corridor. The analysis of the influence and improvement caused by partial refurbishment are not feasible and thus the comparison between the calculated annual heating demand and monitoring data after intervention is not possible.

From the previous analyses was found out a need for :

- Wall insulation
- Enhancment of thermal performance of the windows
- Shading and daylight redirection
- Artificial light by more efficient technology with adaptable colour temperature and automatic dimming
- Sound absorber for enhancement of the room acoustic
- Mechanical air ventilation

2.2 Simulation

As a simulation tool was used the software PHPP. Various interventions were applied and the result were mutually compared. As a result is presented the optimal overall solution for implementation.

2.3 Planned solution

2.3.1 Comparison of PHPP energy efficient refurbishment variants

At the refurbishment works at the school within the 3ENCULT-Project two classrooms so called prototype classrooms were redeveloped to demonstrate the possible energy efficient solutions and to get important experiences for the renovation of the whole school. Because only parts of the building were refurbished so far, there is no clear boundary between the renovated part and the old part. The refurbished prototype classrooms are located in the middle of an arrangement of rooms and the central corridor. The analysis of the influence and improvement caused by partial refurbishment are not feasible and thus the comparison between the calculated annual heating demand and monitoring data after intervention is not possible.

In the following sections of this report are presented different variants considered for refurbishing of the school building. Since the computational model for the status quo was very well corresponding to the reality, the presented consequences of various solutions were very trustworthy as a prediction for the real construction work.

Comparison of different energy efficient refurbishment solutions

To generate the refurbishment variants some inputs located in various sheets have been linked to the new “parameter” sheet where they can be diverse for individual variations. The Figure below was represented with the results of the additional sheet “parameter” of PHPP 2007.

For example the difference between the calculation of variant 1 “before intervention” and variant 2 “Windows” is only the input of the g- und the Ug-value of the glazing of the box-type window in the sheet “WinType”. The changes were carried out in the new sheet “parameter”. This function was developed by Passive House Institute for purposes of the 3ENCULT project.

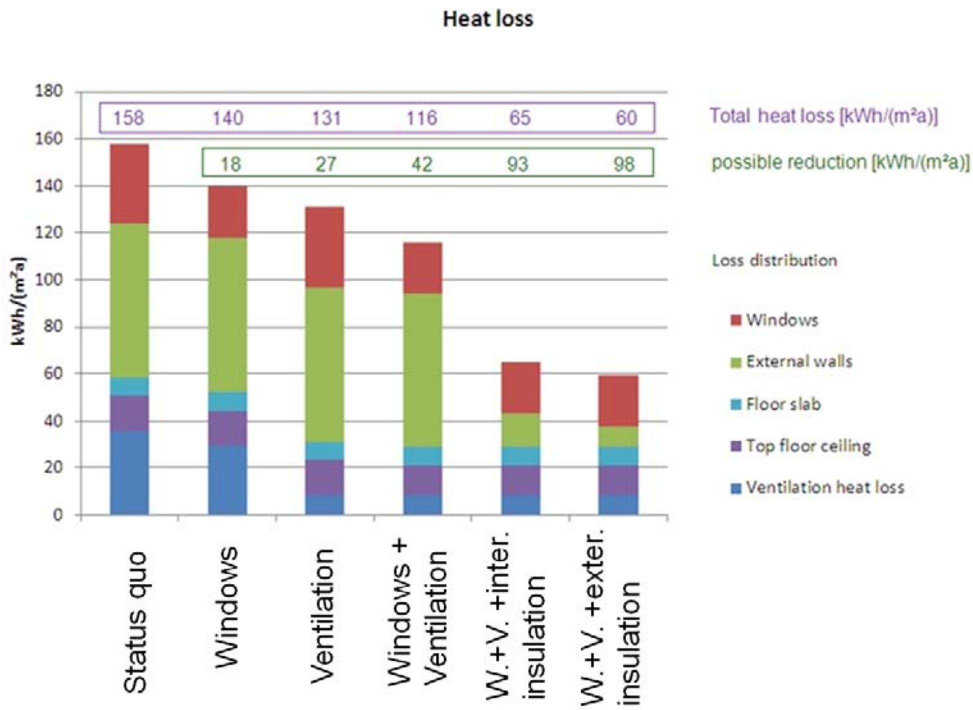


Diagram to compare the heat losses of different refurbishment solutions

The diagram in Figure above presents the selected best examples of reduction variants of the annual heat losses considering transmission heat losses over windows, external walls, floor slab, ceiling on the top floor and the ventilation heat losses. The first column of the diagram shows the heat losses of the status quo - before renovation with a total value of 158 kWh/ (m²a).

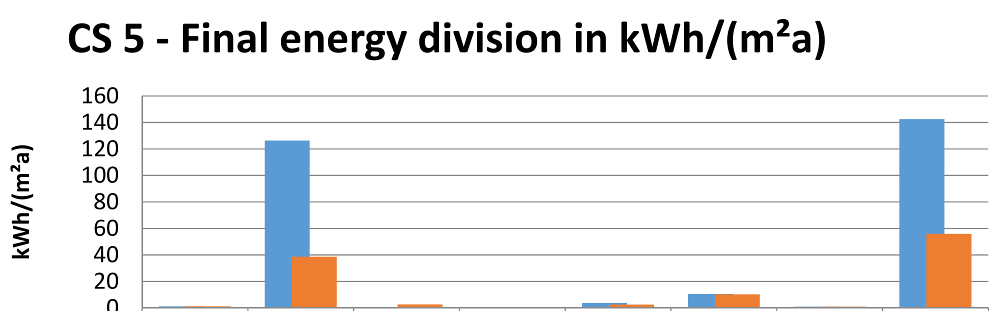
As clearly visible in the diagram the main reductions of the heat losses are possible due to the improvement of the external wall (green part of the column) and the ventilation situation (lowest blue part of the column). After installing 120 mm thick **external insulation** on the external walls the high losses over the thermal bridges would be strongly reduced; e.g. the connection between the load bearing steel beams of the ceiling, the brickwork of the external wall. The external insulation itself has a potential of reduction of 58 kWh/ (m²a) what is the highest impacted at the heat losses in the building. Despite the benefits of external insulation the application is not possible in order to protect the genuine look of the facade. In a case of applying 80 mm of **internal insulation** the second highest reduction would be reached by value of 53 kWh/ (m²a). Nevertheless the losses caused by the thermal bridges would not be solved in this case.

The reduction of 27 kWh/ (m²a), compare to the status quo, is possible due to the improvement of **airtightness** (such as the new seals on windows, or the fixing of leakages in the thermal envelope) and installation of a **new ventilation system** with an energy efficient heat recovery. The study of variants with single ventilation situation and single improved air tightness of the thermal envelope showed that only their combination makes sense otherwise the potentials of these measures is not fully utilized. The installation of energy efficient ventilation in combination with the improvement of the air tightness is the second most effective refurbishment task.

The biggest share of airtightness heat losses are caused by old **windows**, thus its replacement by more airtight once with a better U_g-value would result in reduction of annual heat losses by 18 kWh/ (m²a).

Original box-type windows in the classrooms

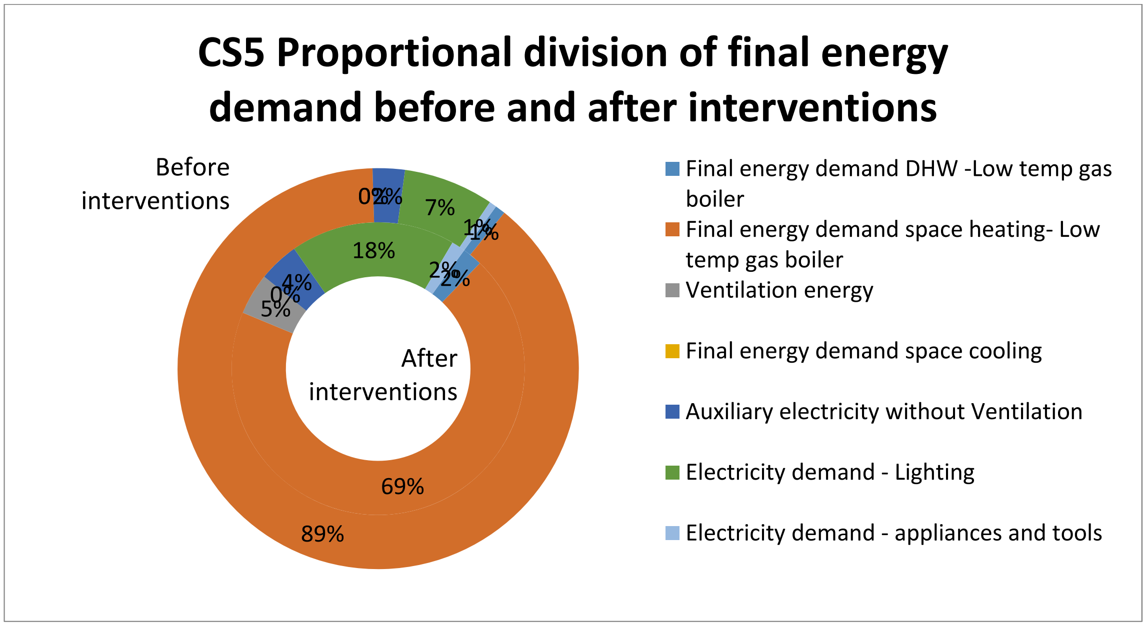
If all previous intervention would be combined with an internal insulation, a total reduction of the heat losses by 91 kWh/ (m²a) should be possible.



	Final energy demand DHW - Low temp gas boiler	Final energy demand space heating- Low temp gas boiler	Ventilation energy	Final energy demand space cooling	Auxiliary electricity without Ventilation	Electricity demand - Lighting	Electricity demand - appliances and tools	Total energy demand (Heating, DHW, auxiliary electricity ,lighting,el....
Before interventions	1,175	126,365	0,000	0,000	3,688	10,343	0,849	142,420
After interventions	1,236	38,545	2,545	0,000	2,497	10,163	0,849	55,835

CS 5 - Final energy division

On the **Fehler! Verweisquelle konnte nicht gefunden werden.**above and below can be seen closed division of energy consumptions outlined by PHPP simulation tool. The variation after intervention contains all proposed energy efficient solutions.

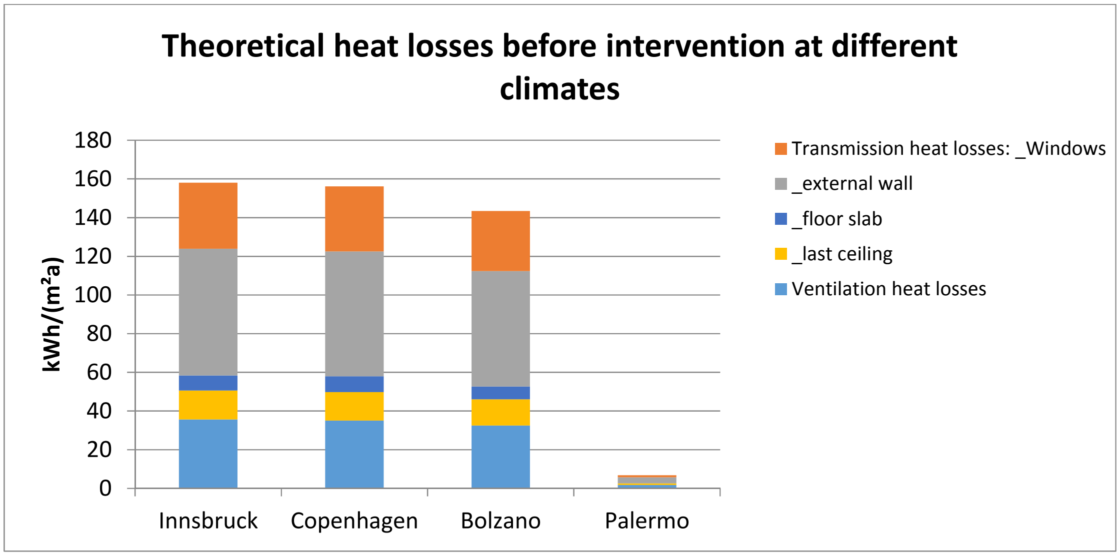


CS5 Proportional division of final energy demand before and after interventions

The energy demand after interventions is higher because the "Marginal Utilisability of Additional Heat Gains" from heating system are smaller.

2.3.2 Comparison of the heat losses of the status before intervention of the Höttinger School located in different climate zones

The figure below presents the annual heating demand for a scenario when the Höttinger School in Innsbruck is placed in 4 different locations. This comparison was carried out when the “Climate Data” sheet was changed in the PHPP calculation file.



Theoretical heat losses before intervention in Innsbruck, Copenhagen, Bolzano and Palermo

From the results shown above is clear that heating needs for the mentioned schools are highly dependent on influences by the local climate, which cools the building during the year.

3 Implementation

3.1.1 Applied energy efficient refurbishment solution in general

In a period when this report was created is the school still under the reconstruction. Foreseen plan of the renovation is very holistic and counts with utilizing of the best variant which contains: Improvement of the airtightness, New windows, Internal insulation and Ventilation system with heat recovery.

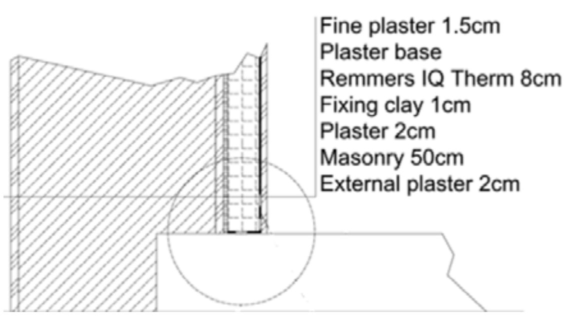
Internal insulation

Two different type of interior insulation were installed and investigated by continuous monitoring of temperatures, humidity and heat flux.

As one of the basic principles of conservation is the reversibility of the interventions, the insulation was glued with loam glue. This way the insulation can be removed using water.

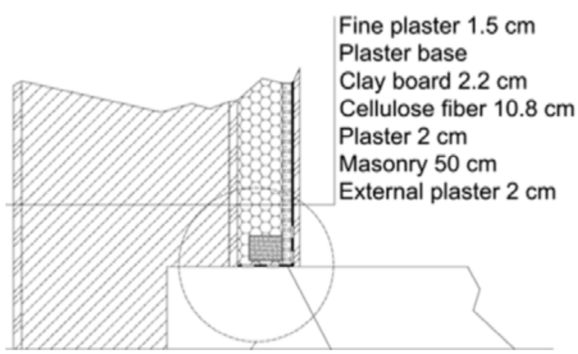
The insulation system shown here is Remmers IQ-Therm 80, which consists of PUR-foam boards with wicks from capillary active calcium silicate.

Thermal conductivity of the capillary active insulation is 0,033 W/mK.



PU-foam insulation in combination with capillary active clay

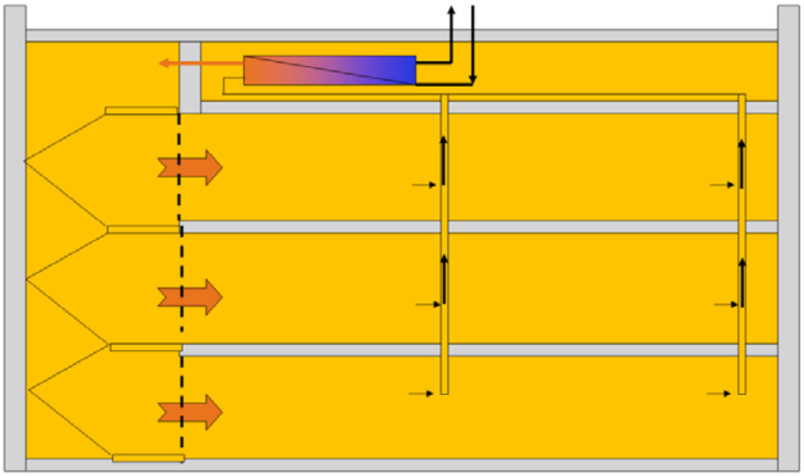
The second system installed in a prototype classroom is made from cellulose fibre blown into the cavity behind a special panel covered with loam plaster. The wooden frame construction is thermally decoupled from the wall by stripes of soft wood fibre (2,8 cm). The drawings show the vertical (left) and horizontal (right) cross section of the interior insulation system. Thermal conductivity insulation is 0,04 W/mK.



Cellulose fibre and clay boards

Ventilation system

In a school building was installed central overflow mechanical ventilation system with heat recovery. Such a system offers high indoor air quality without draft risk. A central system has one heat exchanger for several class rooms.



Cross section of the central overflow mechanical ventilation system concept

The principle of active overflow is not need for vertical or horizontal ductwork for air distribution, because the staircase as well as the corridors is used as an air duct. The compartmentation is solved by fire doors, kept normally open. This designed were two central systems, one placed at the attic; a second unit is planned for the kitchen and the working spaces.

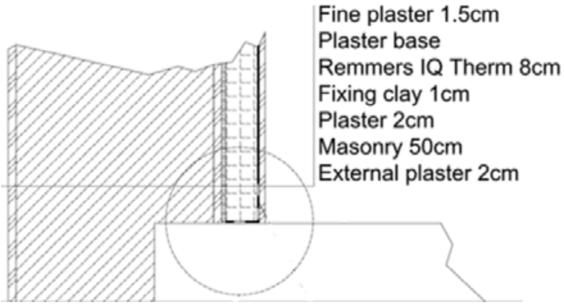
The active overflow principle has some advantages, however, it should be used only in case of listed buildings or if a standard solution is impossible from construction or economic point of view. The reason is, that the ventilation efficiency is lower than in case of a cascade ventilation because of the mixing of the extract and supply air in the corridor.

3.1.2 Applied energy efficient refurbishment solution

Class Room 1

- Wall insulation: Capillary active internal insulation (Remmers IQ-Therm)
- Original windows enhanced with heat protection glass and sealing lips
- Shading and daylight redirection lamellae integrated in box-type window
- Artificial light by LED-technology with adaptable colour temperature and automatic dimming
- Sound absorber made from organic fibre
- Ventilation air distribution via laser perforated textile diffuser

Prototype class room 1



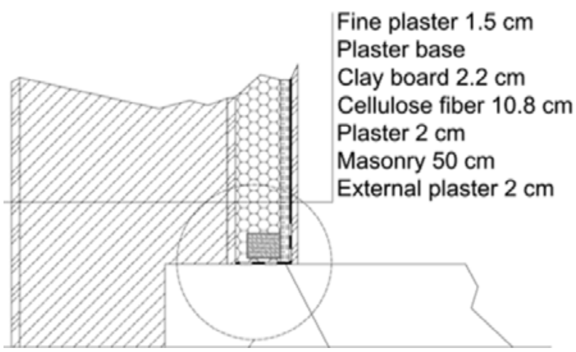
PU-foam insulation (thermal conductivity 0.033 W/mK) with integrated silicate wicks and vapour open plaster glued to the wall with capillary active clay (reversibility)

Daylight redirection to the ceiling by the upper part of the lamellas and sun-blocking at the lower part helps to enhance daylight autonomy without glare problems

Class Room 2

- Wall insulation: Internal insulation by cellulose fibre
- Original windows restored and painted
- Shading by textile screen integrated in box-type window
- Artificial light by high efficient fluorescent lamp and glare suppression
- Sound absorber with integrated artificial light
- Ventilation air distribution homogeneous perforated textile diffuser

Prototype class room 2.

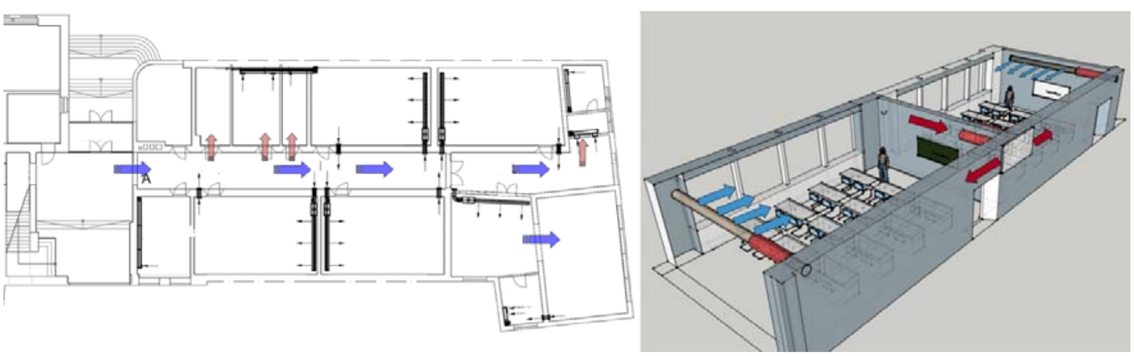


Interior insulation with cellulose fibre (thermal conductivity 0.04 W/mK) and clay boards with clay fine plaster

Silencer and fan-box prototype manufactured by ATREA

3.2 Active overflow ventilation – proof of concept in a listed school building

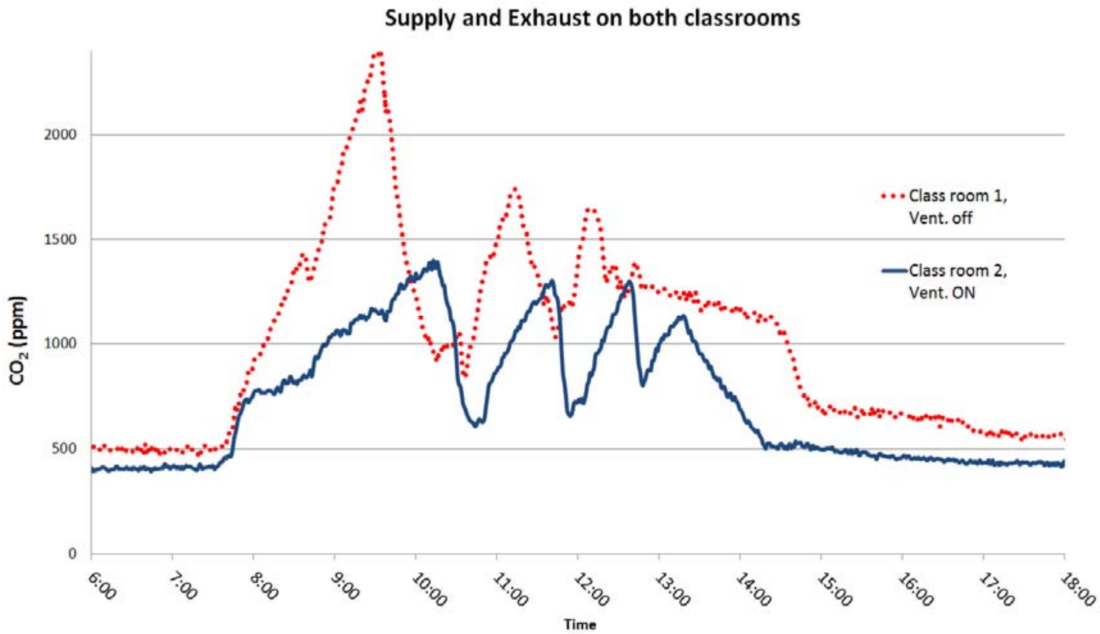
The active overflow principle enables to vent the building with a minimum of ductwork. The supply air from the heat recovery system at the attic flows via the stair case and the corridors to the class rooms. The extract air is ducted from the toilets and wardrobes back to the counter flow heat exchanger to preheat the ambient air. The control strategy is very simple and cost efficient: If the CO2-concentration in the corridor rises, the air flow rate of the central fan of the heat recovery unit rises in order to keep it constant at around 600 ppm. The active overflow fans of the class rooms start operation one hour before the start of the lessons. They are switched off by presence control sensors.



Active overflow principle (supply air from corridor distributed in the class room, extract air is vented back to the corridor via silencers)

Supply air distribution and overflow (upper left), mounting of the fan box (lower right) and overflow silencer (lower right)

4 Post evaluation

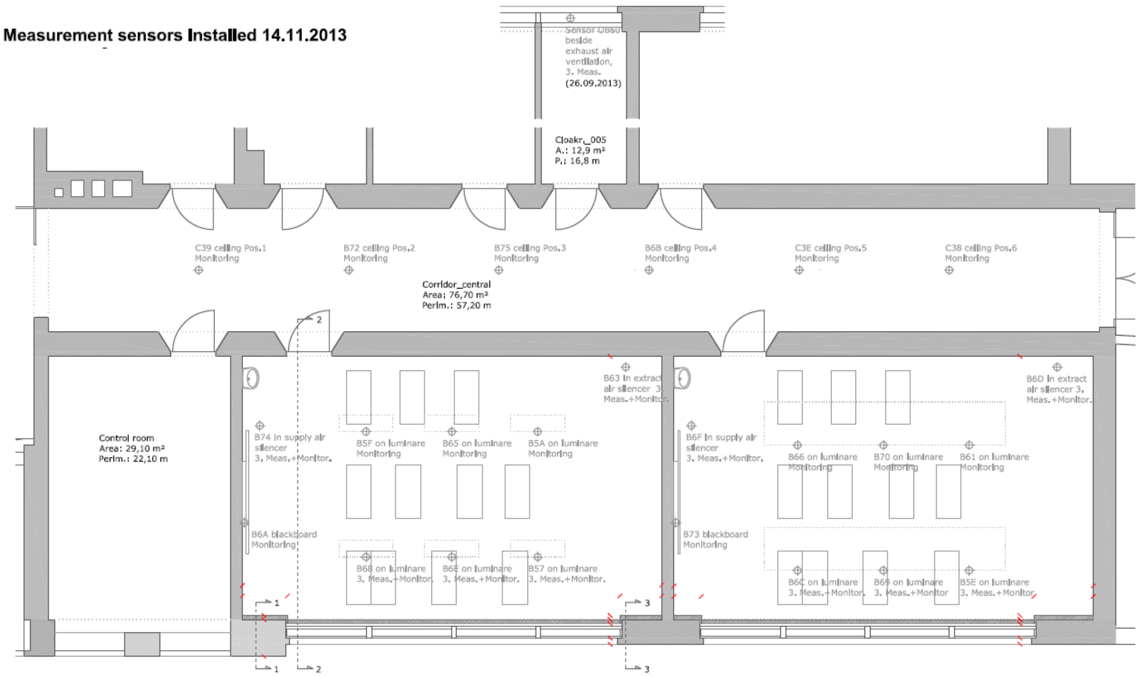


On the Figure above is showed a side-by-side result of CO2 measurement of two identical classrooms where the ventilation was running in Class room 2 and Class room 1 was not actively ventilated.

We can see from the table below that it was possible to improve the indoor climate class from IDA 4 to IDA 3 by adding the ventilation system specially developed for purpose of 3encult project.

	Class name	*Max. value above ambient concentration*	*Max. absolute value with 400 ppm amb. concentr.*
Vent ON	***IDA3***	***600-1000 ppm***	***1.000 – 1.400 ppm***
Vent. OFF	***IDA4***	***>1.000 ppm>1000 ppm***	***>1400 ppm***
Maximum CO_2-Concentrations according to EN 13799			

CASE_STUDY_5, Höttinger Hauptschule, Innsbruck, Austria: FLOOR PLAN M 1:50: Position of CO2-Sensors
(Measurement classroom occupied)



On the Figure above is illustrated the placement of CO2 monitoring sensors in both Class room and in the corridor.

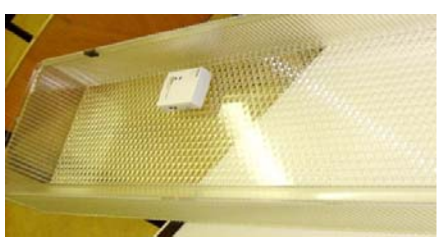
The overall comment is that the system itself performs well, quiet and responsible. The concentration on the corridor seems to be different from what we have expected (probably the air enters the building somewhere else than we have expected). This fact badly influences already concentration of CO2 in the corridor and thus the class room-supply air is not always fresh. This issue will be solved after installation the Air-handling unit when the overflow of fresh air will be controlled.

4.1 Evaluation of the energy consumption

4.1.1 Measured energy consumption

Lighting system

The occupied time as well as the operation time of the artificial light (fluorescent tubes close to the window and close to the inner wall) was measured with loggers (seen on Figure below). For evaluation of the energy consumption, the ON-Duration was multiplied with the electric power of the lighting system.



On/off data logger for artificial lights monitoring placed on luminaire

Table 3: Comparison of new lighting systems installed in the two classrooms

<table>
<tr>
<td colspan="2">Classroom 1
In Classroom 1 was implemented:
▪ LED lighting instead of fluorescent tubes
▪ Automatic dynamic artificial and daylight control (dimming)
▪ High-end solution (colour temperature control)
▪ Reduction of energy use by 18%</td>
<td></td>
<td colspan="2">Classroom 2
In Classroom 2 was implemented:
▪ Artificial light by new fluorescent lamps
▪ Energy efficient day light dependant control (ON/OFF strategy)
▪ Light integrated in sound absorbers
▪ Reduction of energy use by 26%</td>
</tr>
<tr>
<td>Energy consumption old [kWh/m²a]</td>
<td>4,31</td>
<td></td>
<td>Energy consumption old [kWh/m²a]</td>
<td>5,4</td>
</tr>
<tr>
<td>Energy consumption new [kWh/m²a]</td>
<td>3,53</td>
<td></td>
<td>Energy consumption new [kWh/m²a]</td>
<td>3,98</td>
</tr>
</table>

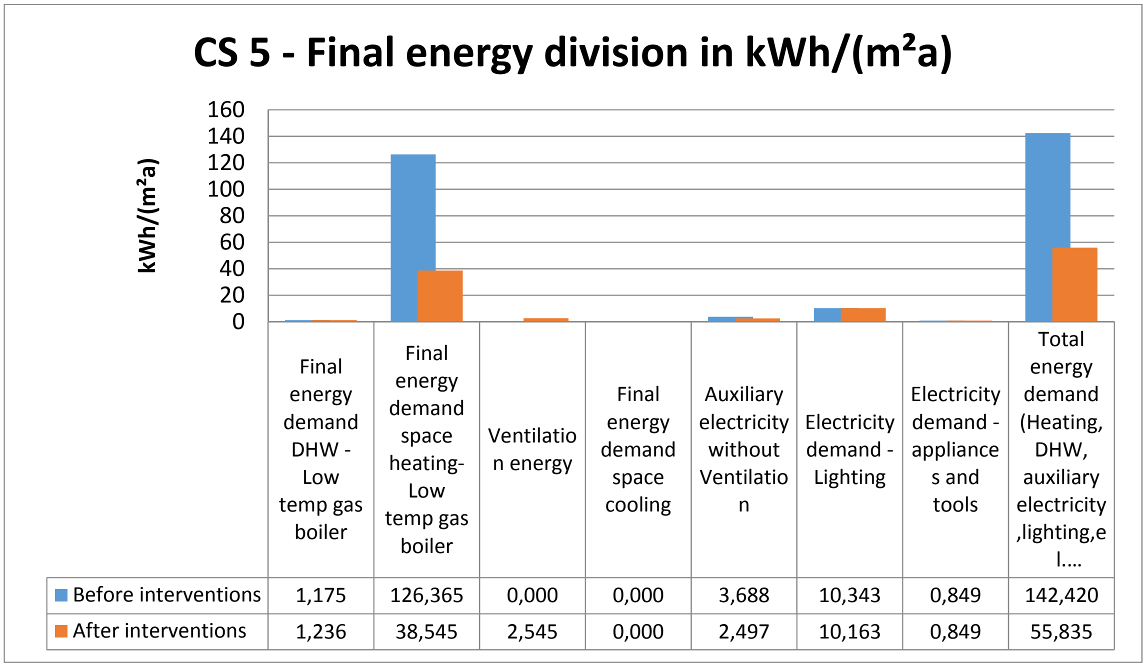
Illustration of situation before and after installation of the new lighting system in the two classrooms

The acoustics in historic buildings is part of its individual characteristics. It is strongly influenced by the equivalent sound absorption areas of all materials/surfaces in the space. The higher the total equivalent sound absorption area of the room, the lower is its reverberation time. As the reverberation time strongly influences the speech intelligibility, it should be reduced according to the use of the room (e.g. auditorium, class room). In case of historic buildings, covering of surfaces with sound absorbers is mostly not acceptable (e.g. for architectural reasons, stucco or paintings etc.) or not suitable (covering the thermal inertia of ceilings or walls results in reduced summer comfort). In this case vertically suspended absorbers (so-called "baffles") are useful, if the design fits to the room and its architecture. Within the 3ENCULTproject special absorbers were developed for the prototype class rooms in CS5 which work well also in combination with the daylight redirection.

Acoustic elements (made by ORGANOID) in combination with daylight redirection)

4.1.2 PHPP Calculated energy consumption

If all previous intervention would be combined with an internal insulation, a total reduction of the heat losses by 91 kWh/ (m²a) should be possible.



	Final energy demand DHW - Low temp gas boiler	Final energy demand space heating- Low temp gas boiler	Ventilation energy	Final energy demand space cooling	Auxiliary electricity without Ventilation	Electricity demand - Lighting	Electricity demand - appliances and tools	Total energy demand (Heating, DHW, auxiliary electricity ,lighting,el....
Before interventions	1,175	126,365	0,000	0,000	3,688	10,343	0,849	142,420
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CS 5 - Final energy division

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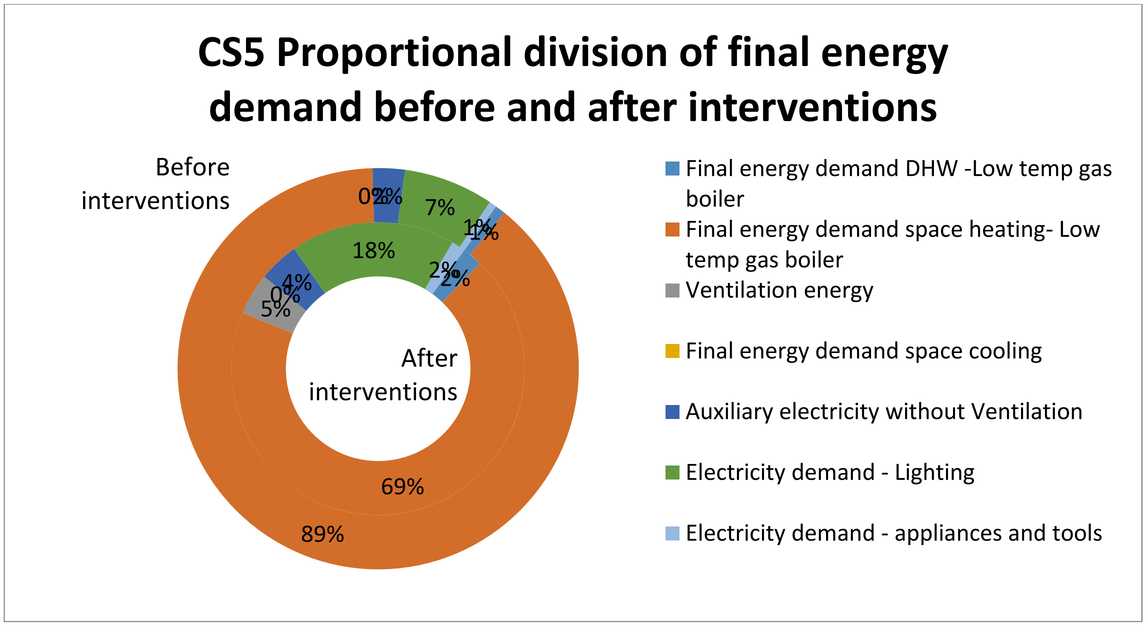


CS5 Proportional division of final energy demand before and after interventions

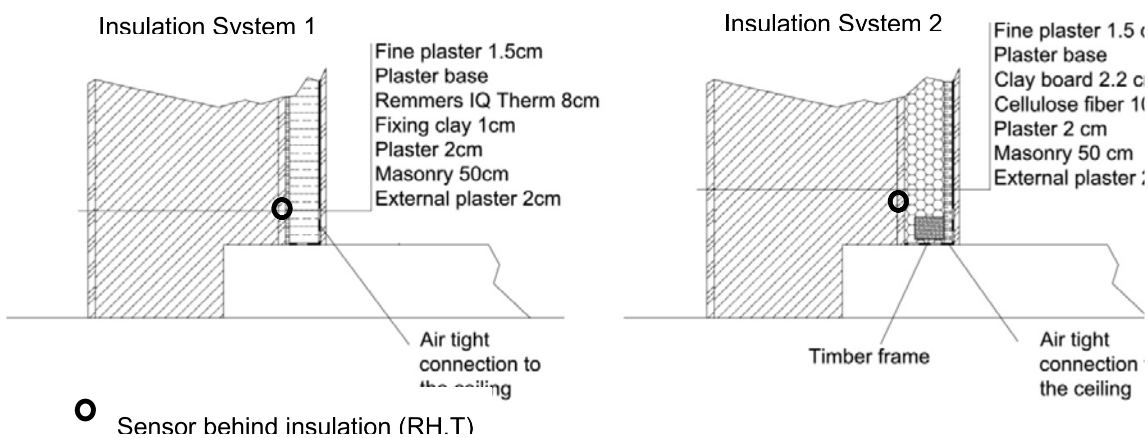
The energy demand after interventions is higher because the "Marginal Utilisability of Additional Heat Gains" from heating system are smaller.

See chapter 2.3.1.

4.2 Evaluation of the construction´s situation

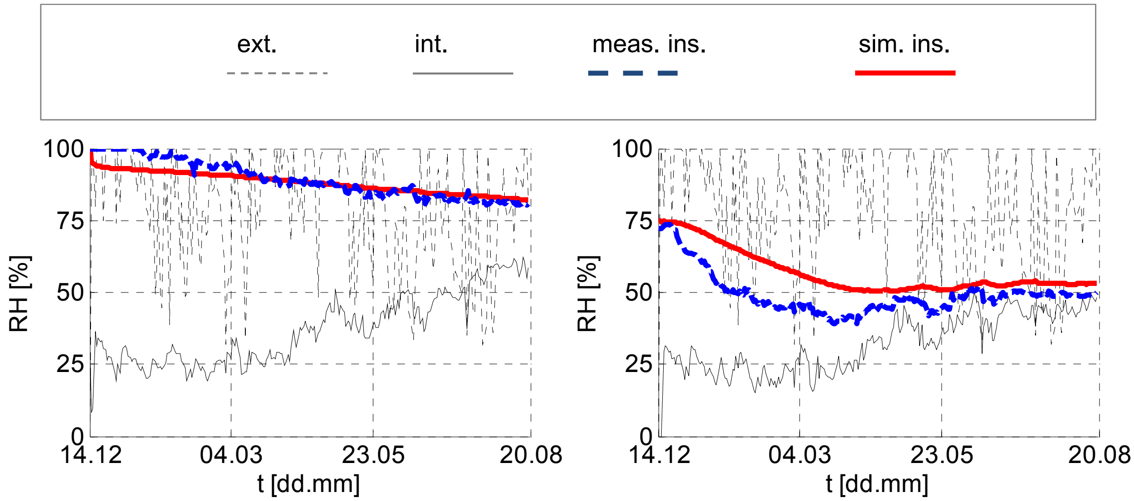
4.2.1 Evaluation of Delphin hygrothermal simulation and evaluation of monitoring data into the construction

In November 2012 two classrooms have been provided with different internal insulation systems for testing. The employed insulation materials are PU-foam in combination with capillary active channels and clay glue for the first system (IQ-Therm system, figure below, left) and blow-in cellulose for the second one (, right). Capacitive sensors have been installed for monitoring of temperature and relative humidity at different positions (between insulation and masonry, at the internal and external surfaces and in the surrounding ambient). The analysis of the measured data aims to select the most appropriate solution to be employed for the retrofitting of the whole building, with respect to the moisture damage risk.



Vertical sections of the wall-ceiling junction. Insulation system 1: PU-foam insulation in combination with capillary active clay (left). Insulation system 2: Cellulose fibre and clay boards (right)

In figure below the temporal evolutions of measured relative humidity behind insulation for both the test-rooms are reported and compared with simulation results. The simulations have been performed with a finite-volumes based program ["Delphin Software," 2011], employing 2D models. figure below reports also the internal and external relative humidity values. The numerical results show satisfactory agreement with the measured values, demonstrating that the assumptions on the material data and boundary conditions used for the simulation are adequate. From the temporal evolution of relative humidity, it can be observed that both constructions are drying. However the first test-room (figure below, left) presents values of relative humidity under the insulation starting from 100%. This can be explained, considering that the fixing-clay used for the insulation boards has to be applied wet. The very slow drying process of the construction can represent a drawback of this system, since the favourable conditions for germination of mould are present behind the insulation over a long period of time (relative humidity over 75% all over the monitored period). Hence, air voids behind insulation, inside which germination could start, have to be carefully avoided.



Evolution of the relative humidity (left: system 1, right: system 2) over the monitored time period (Dec.2012-Aug.2013). External (ext.) and internal (int.) values as well as measured (meas.) and simulated (sim.) values behind insulation (ins.).

The cellulose-based system (figure above, right) presents non-critical values of relative humidity, therefore it can be considered appropriate for this application. However, it has to be noticed that the internal relative humidity remains very low during the whole winter period (around 25%) due to the moderate humidity sources and active ventilation in the classrooms. Numerical simulation has shown that higher internal moisture sources or limited air exchange rate can lead to modified conditions under the insulation [Janetti et al., 2013], hence mechanical ventilation is recommended.

4.3 Evaluation of Impact on cultural heritage value

4.3.1 Impact on the appearance

The overall impact on the appearance will be neglect able since the external appearance was the criteria of the conservations. The improvement of building envelope will be done from inner side or by enhancement of façade components without any visible difference.
The impact on the appearance is described below in a list of interventions that were applied in the two demonstration classrooms:

Insulation and building tightness

Baseline situation: About 40% of all heat transmissions of the building are passing through the exterior walls. A remarkable improvement of the energetic building performance needs a reduction of the heat transition which can be managed with either interior or exterior insulation.
Authority (BDA):
Exterior Insulation is inacceptable in any case.
In some cases interior insulation is acceptable to make an insulating inner wall if there are no panels or other architectural details. This intervention must be removable without damaging the genuine structure.
Architect:
Facing the limited budget, existing/raising problems in this special case study with building physics (thermal bridges, condensation within the construction) and the risk of interior insulation, causing

additional humidity into the support area of the floor slabs nearby the magnesia screeds, the architect prefers exterior insulation. He assumes that if done in a sensible way which does not change the proportions of the building, exterior insulation as a removable wear layer could be an option not only to solve the existing problems of thermal bridges and condensation within the construction but also to preserve the genuine construction from further damages and to keep the genuine heating distribution and radiators in place.

Interventions done

Interior insulation to existing outer walls: Two different solutions are applied and tested.

Room 1: a PUR foam board glued with loam to the wall, with integrated silicate wicks and vapour open plaster, bringing humidity from within the wall to the interior warm side.

Room 2: a wooden frame substructure, filled with blown in cellulose insulation, covered by loam boards and loam plaster.

Air tightness was improved adding plaster/window-connections.

Benefit: reduced heat transition

Disadvantage: thermal bridges can´t be solved, risk of condensation within the construction, high costs due to the necessary removing of the heating distribution and radiators, loss of genuine heating distribution, area and volume

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Windows and sun shading

Baseline situation: existing windows are only partly genuine, already damaged and generally in a bad state of repair. Existing load bearing steel columns within the window lines, unprotected against fire impact and also severe thermal bridges. Leakages caused by not airtight plaster/windows-connections. The original shading - a roller blind mounted within the two wing layers – is inefficient and damage-prone.

Authority (BDA):

The genuine windows should be preserved.

Due to the already done interventions on the old windows, the effort to repair/restore the old windows is much higher than to rebuild them, so reconstructing them could be a solution in this special situation (but is not a general advice!). The double glazing for the inner wings is acceptable.

The new daylight guiding venetian blinds mounted within the wings are acceptable during the time of measurements. The intervention can't be assessed at the time for the whole building. It can be considered, if it doesn't disturb the buildings main heritage value.

Architect:

Prefers an improved reconstruction of the old windows following the old drawings and in this way receiving a higher quality in a more cost efficient way. Attention has to be paid to the steel columns (I-girders) running vertically through the window lines. In accordance to the new building laws, they have to resist a fire impact of at least 90 minutes and have to be protected either by fire protecting coat or plasterboard.

In the eventuality of an exterior Insulation, the windows have to be shifted to the outside, keeping the proportions of the existing window embrasures.

Interventions done

Room 1: Demounting/Repairing/restoring/improving/mounting of the genuine box-type windows. The upper outer wings were rebuilt according to the investigated genuine state of construction.

To reduce the leakages and heat transition in the layer of the inner wings additional window seals were added and the thermal quality of the glazing (double glazing instead of existing single glazing) improved.

Where the windows had been demounted, the steel columns between the windows elements were painted with a fire protecting coat, capable to resist 90 minutes of fire impact and also isolation added to reduce the thermal bridges.

The old blinds were replaced by new daylight guiding venetian blinds, supporting the artificial lighting in an energy efficient way.

Room 2: The old windows were painted, the roller blinds repaired.
Benefit: regain of the genuine optic and function of the exterior upper wings, reduced heat transition, reduced solar gains, efficient use of daylight
Disadvantage: difficult adjustments of the daylight guiding shadings, thermal bridges caused by steel columns can only be solved, if they are situated within the warm side of the construction, risk of condensation within the construction especially if not airtight, high costs due to the necessary demounting/mounting of the windows, additional weight of the double glazing could overstrain the genuine Iron strap fittings of the windows, these should be reinforced.

Heating and cooling

Baseline situation: The measured heating demand, being about 25% higher than the calculated one, resulted mainly out of not adjustable room temperatures, caused by the enormous thermal mass (about 400-500 kg) of the radiators with a flow temperature of about 85 degrees Celsius. So in winter, room temperature was regulated by opening the windows. This caused very dry air and very uncomfortable conditions for pupils, having their seats near the window line. In summer especially on the west facades the solar gains are high, resulting in overheating.
The heating central is placed under the roof, providing not only the school but also the public swimming bath in the neighbourhood. Heat losses are high. It is intended to separate the swimming bath from the heating central and to construct a new heating central for both: the actually new built school SPZ in the south of the gym and the old school.
Authority:
The genuine tube-radiators are essential elements of the interior design and must be preserved.
Architect:
To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the existing problems with dry air and discomfort should be improved: the radiators, essential element for the genuine interior design must be optimised to fit to the demands of comfort. Within the thermal refurbishment the flow temperature should be lowered to a level, which allows a feasible integration of renewable energies. The thermal mass of the radiators should be reduced. Also the thermal mass of the floor slabs should be used as a thermal buffer to prevent expensive active cooling.
Interventions done
In both rooms the heating distribution was separated from the main distribution line: a heat exchanger and circulation pump was interposed between main distribution line and separated heating circuit to simulate lower flow temperature.
The ceilings were kept free from interventions (as acoustic drywall suspended ceilings) to keep them in use as thermal buffer.
Room 1: inlets mounted in the radiators, reducing the volume of the heating water to a third, improving the adjustability, flow temperature lowered to 45°C adapted to reduced heat demand (interior insulation and improved thermal quality of window line),
Room 2: flow temperature 55°C adapted to reduced heat demand (only interior insulation)
A replacement of the old heavy tube radiators was discussed, a new sample tube radiator ordered but not deliverable in the needed construction length of about 8m due to static problems (fixed diameter of the tubes).
Benefit: increased comfort, improved adjustability, reduced heat losses
Disadvantage: high efforts, high costs, still high thermal masses of the radiators.

Ventilation

Baseline situation: insufficient natural ventilation through windows. Measurements have brought up, that even with leakages the indoor air quality during lessons is insufficient and mechanical ventilation necessary to fulfil the obliged value with a maximum of 1500 ppm CO_2.

Authority:
Window is designed with the intention to be opened. An additional ventilation system with the least possible impact on the genuine structure (using f. ex. secondary rooms for distribution) is conceivable but has to respect the high quality of the genuine interior architecture. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.
Architect/Scentist:
Architect: To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the existing problems with air quality should be improved.
Scientist: Proposes a cascade ventilation system, using the space of the old heating central under the roof, using the main stairway and the corridors, bringing in the fresh air, guiding/collecting the waste air through pipes situated in secondary rooms as wardrobes, washrooms, toilettes, up to the roof, using a heat exchanger to warm up the fresh air.
Interventions done
Room 1/Room 2: Installing of ventilators with integrated silencers, textile hoses for air distribution within both classrooms.
Wardrobe: Installing of an exhaust ventilator to simulate the circulation of the air streams and pressure differences within the corridor.
Benefit: increased air quality, reduced heat losses
Disadvantage: costs, some impact on genuine interior design.

Electricity/Lighting

Baseline situation: existing electrical installation is not in accordance with technical standards and guidelines and not capable to fulfil the demands of new technical equipment and common IT solutions due to new methodologies in teaching. Insufficient lighting-conditions in the classrooms on two-third of the tables (measured values of about 150 Lumen, obligation for classrooms minimum of 300 lx)
Authority:
The intervention can't be assessed at the time. If the necessary documentation is obtained, it can be considered, if it doesn't disturb the buildings main heritage value.
Architect/Scentist:
Architect: To provide pupils and teachers with an optimum setting for learning in the modernized rooms, the electrical installation has to fulfil the demands and has to be flexible enough to implement further possible needs.
Energy efficient solutions should be preferated.
Interventions done
In both classrooms IT-electrical installations were added as a provisional arrangement, the existing electrical installation supplemented.
Room 1: The old blinds were replaced by new daylight guiding venetian blinds, supporting the artificial lighting in an energy efficient way. A new lighting system was installed, using LED balanced colour lamps and wallwasher.
Room 2: The old blinds were kept. A new lighting system was installed within suspended acoustic drywall absorber elements, using energy efficient fluorescent tubes of the newest energy efficient generation TC-L and 6*2 x 24/49/54 W T16 tubes and wallwasher.
Benefit: demands fulfilled, improved lighting situation, reduced electricity costs
Disadvantage: character of provisional arrangement, costs of LED balanced colour lamps, some impact on genuine interior design.

Acoustics

Baseline situation: very long reverberation times, lack of understandability

Authority:
The intervention can't be assessed at the time. It can be considered, if it doesn't disturb the buildings main heritage value.
Architect:
Improving of understandability is absolutely necessary for an optimum setting for learning.
Interventions done
Room 1: bio-fiber absorbers mounted on the innerst third of the ceiling (rest of ceiling used for reflecting daylight)
Room 2: dryboard absorbers combined with lighting solution
Benefit: acceptable reverberation times in both classrooms
Disadvantage: some impact on genuine interior design

4.3.2 Reversibility of measures

The reversibility of planed interventions could be divided in two groups:

- First are the technical measures like ventilation of lighting system that can be simply dismounted and the wall perforation could be blinded.
- Second group covers the internal insulation that can be dismounted as well but the interior surfaces would need a complete reconstruction.

4.3.3 Overal rating

Historic buildings are an extreme case of protecting of the original state of the monument during its reconstructions. This fact makes the work of engineers more difficult but in the same time creates challenges to overcome and kicks the demand for novel and innovative solutions. Such an approach shows the exemplary way for similarly "restricted" objects, or likewise appeal all types of renovations for its practicality.

The Case studies of the 3ENCULT project are situated all over Europe. The outcomes are not solely applicable for the building types representing regional traditions but also for the conservation point of view of any site. Although the heritage legislation in Europe acts in accordance with overall accepted charters and guidelines. Moreover the organization and evaluation is different in several countries. Nevertheless the following list of recommendations proposed by the Austrian guideline (BDA Austria 2011) “Energieeffizienz am Baudenkmal” is generally accepted. Below there is given the translated text of 10 basic rules about energy measures on heritage buildings form conservation point of view:

1. THE ORIGINAL Superior Objective of monument conservation is the unchanged preservation of the historic stock and its appearance as far as possible. In the case of necessary changes the preexisting state, the measures and the state after the measures are to be documented under preservation standards.
2. ANALYSIS Most of the monuments exhibit a quite heterogeneous constitution grown in time. In the course of the planning a complete knowledge on the stock as well with respect to structurally as with respect to building physics is essential.
3. OVERALL PROJECT Measures shall be based on a holistic planning and not focus on single actions. The achievement of single U-values or theoretical demands on thermal heat is not adequate. The aim is to reach the sensible improvement of the total energy budget of the building.
4. USER BEHAVIOR The aim of the energetic retrofit shall not be based of specified guidelines like the standardized Energy Performance Certificate, but has to refer to the practical use and the behavior of the user in the specified object.
5. INDIVIDUAL Monuments need individual solutions instead of standard formulations. This asks all parties involved the readiness of probably increased planning efforts, an improved quality assurance and intensified communication with and between expert, owner, investor and monument preservation until the termination of the measures.

6. REPAIRS The first step is to look for sources of errors on the monument do repairs and reactivate original functions to promote the historic ideas. No until the chances of restoration exploited one may decide on amendments or exchanges.
7. MATERIAL ACCORDANT Necessary amendments in the course of energetic improvements have to be accordant to the existing materials.
8. FAULT TOLERANT Given the fact that as well in production as in use there is never ideal conditions fault tolerant, repairable and reversible constructions are preferred.
9. RISK FREE A long standing damage freeness is to guaranteed. For this often the participation of experts in building physics with major experience in monument conservation is necessary. Innovations and experiments on monuments are solely justifiable if this is included in serious scientific projects. In other respects it is imperative: better less and save - than much and risky.
10. FAR-SIGHTEDNESS/VISION Measures on a monument queue in a stepwise development of the former centuries. Preservation forces all participants a vision beyond liability or time of depreciation.

Keeping these basic recommendations in mind, new solutions, concepts and ideas come up, suitable for both, the conservation of our built heritage as well as for climate protection by energy efficiency and use of renewables.

5 Summery and conclusion

As decided by the building owner (IIG), the whole school building will be refurbished within the next two years. The school building is part of the upcoming EU-demonstration project SINFONIA with a total area of 66.000 m² of dwellings and school buildings to be refurbished in Innsbruck (A) and Bolzano (I).

The building diagnosis as well as the research and investigations on possible interventions (especially in terms of energy efficient solutions) performed within 3ENCULT is an important basis for future decisions. The evaluation of the losses of the thermal envelope showed, that the effect of a wall insulation (together with a significant enhancement of the airtightness of the building) is one of the key issues for comfort and energy efficiency. The installation of a heat-recovery ventilation is necessary for air quality reasons and to avoid damages by moisture at the same time. The active overflow concept in combination with a central heat recovery at the attic turned out to be a well performing solution. The combination of shading and daylight redirection integrated within the box-type-window avoids glare and overheating and enhances the daylight autonomy.

The solutions tested in two prototype-class rooms were measured and evaluated. Moreover a test installation of a reversible PV-System will give information on the visual aspect (both, from architectural and conservational point of view) as well as the electrical performance under real conditions.

All of these results, as well as the cost estimation from the prototype installations in the class rooms and at the roof allows for a detailed forecast of investment, comfort and payback to be expected for the full scale refurbishment. Most of the solutions will be put into practice as suggested within the 3ENCULT projects, some of them (such as the LED lighting) might be too expensive at the moment, but might be applied within future projects in a similar way.

The interdisciplinary work of the case study team will continue within the next years in order to find good solutions from conservational, architectural and energy point of view.

The 3ENCULT project finally found a common language and mutual understanding of all of the different disciplines. This multidisciplinary approach is essential for the huge task of preservation of our cultural heritage and natural livelihoods for future generations.

Literature

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[Pfluger 2011] Pfluger R., Werner M., Feist W.: Optimisation of daylight and artificial light in cultural heritage Hauptschule Hötting in Innsbruck, Austria (3ENCULT Case Study 5). In: Energy Management in Cultural Heritage. International Conference, UNDP Croatia, Dubrovnic, 6.-8.04, 2011

6 Annex 1 - PHPP calculation for status pre-intervention

CS 5: *Aspect*	*Before*	*After*	*Unit*	**PHPP** *Before interventions*	*After interventions*	*Unit*
Treated floor area AREA:	*4089,860*	4089,860	m²			
Energy demand						
Space heating demand	*528983,686*	*157411,166*	kWh/a	*129,340*	*38,488*	kWh/(m²a)
Heating load non-residential	*62,225*	*21,826*	W/m²			
Frequency of overheating (> 25 °C)	*0,000*	*0,000*	%			
Space cooling demand	*78,373*	*12,200*	kWh/a	*0,019*	*0,003*	kWh/(m²a)
Domestic hot water demand	*4458,517*	*4686,201*	kWh/a	*1,090*	*1,146*	kWh/(m²a)
Interior temperature winter:		17,44558208	°C			
Interior temperature summer:		25	°C			
Average building envelope quality						
Average U-value of walls	1,804	0,350	kWh/a			
Average U-value of external insulation to ground	*1,804*	*0,350*	W/(m²K)			
Average U-value windows and doors	*2,162*	*1,373*	W/(m²K)			
Average U-Roof/Ceiling - Ambient	*0,540*	*0,455*	W/(m²K)			
Average U-Floor slab/ basement ceiling	*2,350*	*2,350*	W/(m²K)			
Pressurization test result n50	*4,4*	*0,6*	1/h			
Measurable - Final energy need						
Final energy demand DHW -Low temp gas boiler	*4805*	***5057***	kWh/a	*1,175*	*1,236*	kWh/(m²a)
Final energy demand space heating-Low temp gas boiler	*516815*	*157643*	kWh/a	*126,365*	*38,545*	kWh/(m²a)
Ventilation energy	-	*10411*	kWh/a	-	*2,545*	kWh/(m²a)
Final energy demand space cooling	-	-	kWh/a	-	-	kWh/(m²a)
Auxiliary electricity without Ventilation	*15083*	*10211*	kWh/a	*3,688*	*2,497*	kWh/(m²a)
Electricity demand - Lighting	*42301*	*41563*	kWh/a	*10,343*	*10,163*	kWh/(m²a)
Electricity demand - appliances and tools	*3472*	*3472*	kWh/a	*0,849*	*0,849*	kWh/(m²a)
Total energy demand (Heating, DHW, auxiliary electricity, lighting, el. Appliances)	*582476,630*	*228355,935*	kWh/a	*142,420*	*55,835*	kWh/(m²a)
Primary energy need						
Primary energy demand DHW	*5285,492*	*5562,244*	kWh/a	*1,292*	*1,360*	kWh/(m²a)
Primary energy demand space heating	*568496,873*	*173406,877*	kWh/a	*139,002*	*42,399*	kWh/(m²a)
Ventilation energy demand	-	-	kWh/a	-	-	kWh/(m²a)

Primary energy demand space cooling	-	-	kWh/a	-	-	kWh/(m²a)
Auxiliary electricity - without Ventilation	*39215,993*	*26547,683*	kWh/a	*9,589*	*6,491*	kWh/(m²a)
Electricity demand - Lighting	*109982,819*	*108064,430*	kWh/a	*26,892*	*26,423*	kWh/(m²a)
Electricity demand - appliances and tools	*9027,564*	*9027,564*	kWh/a	*2,207*	*2,207*	kWh/(m²a)
Total energy demand (Heating, DHW, auxiliary electricity, lighting, el. Appliances)	*732008,740*	*322608,798*	kWh/a	*178,981*	*78,880*	kWh/(m²a)

7 Annex 2 - Description of the monitoring system

In the first step of the project, the monitoring system for the CS5 was deployed for the diagnosis of the status of the building. The problem in this network is the lack of Internet connection. Therefore, the application is not able to connect in order to download data logs. However, this information is shared in the FTP Server on the CS7 in order to enable the reading of values from the Central Server. Thus, all the files (notice the first monitoring phase is finished) are in the server. But, the complexity of the application is the diversity of log files, although all of them txt files. These txt files are named in the way, the application is able to know the sensor, place and the kind of measurements when naming the variables.

First of all, for the measurements of the daylight and artificial light of the classrooms, a matrix is drawn in the log file, as it is printed in the Table 4. In the first row and column, it is detailed the coordinate in where the data-point is measured.

	0.00	**0.92**	**1.84**
0.00	109	170	245
0.91	142	198	266

Table 4: Light measurements in the classrooms for the case study 5

For the measurement of the status of the entrance or windows side and lights, the format is quite similar. The sensor offers several lines where the information is read. An example is in the Table 5 where the difficulties are related to filter the line which contains the measurement of the variables.

Number	Date	Time	Line1	Line2	Line3
310	16.03.2011	08:36:40	-	-	1

Table 5: Status measurements in the classrooms for the case study 5

For the remaining values such as thermal comfort and external measurements of temperature and relative humidity the format is the same than the status. That is to say, all the files show a header where the value measured can be found out. Mapping these headers and the readings, the application is able to store the suitable value, units and sensor related. [1]

7.1 Monitoring Concept

Please see also Deliverable D4.2, 4.3 and 4.4

7.1.1 User comfort by CO2-concentration - Monumental School, Innsbruck

The “NMS Hötting” in Innsbruck (Austria), a listed four-story school building (Table 6), was chosen as a 3ENCULT case study as an example of a building from early modernism. For demonstration and

[1] 3encult Deliverable D4.4

verification of energy efficient solutions two classrooms of the building have been renovated and provided with a monitoring and BMS system (for artificial- and daylight control as well as ventilation).

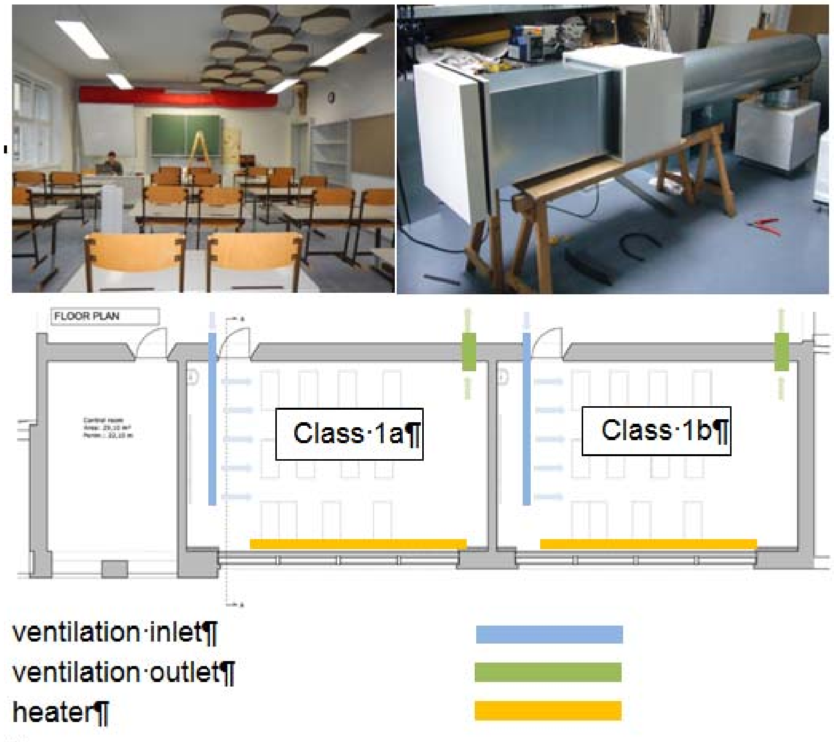
Building	NMS Höttinger (New Middle School). Year of construction 1929/30. Innsbruck, Austria.
Utilization	School building
Building equipment present	• Radiators (water based) • Active overflow ventilation system with central heat recovery • Daylight redirection and shading lamellas (classroom 1) • Shading screen (classroom 2) • LED lighting system (classroom 1) • Luminescent screen tubes lighting system (classroom 2)
Building equipment optionally possible	• Central or decentral heat recovery system • Shading lamellas
Top priority for control	1. User comfort (thermal and visual) 2. Energy saving 3. User friendliness

Table 6: Brief description of the building and building equipment

Besides the reduction of thermal losses and reduction of electrical consumption for artificial light, a special focus is on adaptation and optimisation of the ventilation system which is controlled by means of CO_2–concentration sensors and presence sensors. Criteria used for the control system are shown in figure below.

Critical alarms and requirements of construction elements, user comfort and energy demand

As ventilation system, the active overflow principle was transferred to school buildings. In this case the high flow rate (around 700 m³/h) calls for a dedicated air distribution system to avoid draft risk and excessive airborne noise. In order to minimise the ductwork within the building an active overflow system takes the air from the corridor to the class room and vents the extract air back to it. A central heat recovery system ventilates the staircase and the corridors with preheated fresh air (figure below).



Test-classroom (upper left); Active overflow prototypes with active overflow and silencer manufactured by ATREA (upper right); Ventilation schema (bottom);

Two different control strategies for the ventilation system were considered. The first one is based on the use of time schedules for the control of the fans (figure below). This strategy presents low installation costs, since no sensor is necessary, but it is not flexible in terms of changes related to the real occupation and the time schedules.

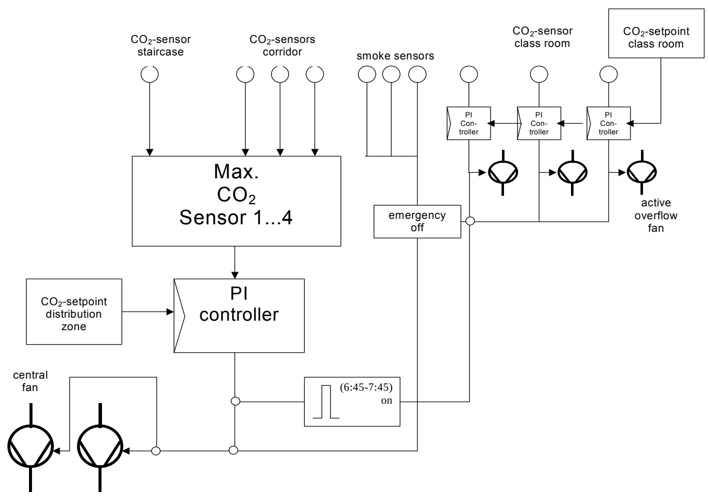
Occupation time schedules for the prototype class rooms

For this reason a second strategy was considered, based on monitoring of the CO_2-concentration. The indoor air quality is categorised according to EN 13799 (figure below) in 4 classes, IDA2 is rated as good and IDA3 as moderate air quality. If a CO_2-Sensor would be installed in each class room, the active overflow fans could be controlled according to a given set point (e.g. IDA 3).

CO_2-class name	Max. value above ambient concentration	Max. absolute value with 400 ppm ambient concentration
IDA1	<= 400 ppm	<= 800 ppm
IDA2	400 - 600 ppm	800 - 1.000 ppm
IDA3	600 - 1000 ppm	1.000 – 1.400 ppm
IDA4	>1.000 ppm>1000 ppm	>1400 ppm

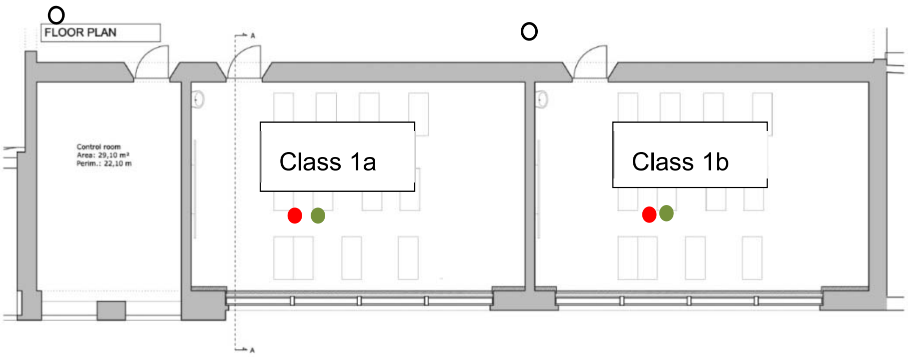
Occupation time schedules and Requirements for indoor CO_2 concentration according to EN 13799

This control strategy enables the most efficient demand control for each of the active overflow fans, especially if the number of pupils varies a lot. The drawback however is the high costs for investment and maintenance (re-calibration and substitution). As shown in figure below the flow rate of the central fans are controlled via CO_2-sensors in the corridor and class rooms.



Control scheme for central fans and active overflow fans in case of CO_2-measurement in each class room

The third (most simple, cost effective and robust) control strategy is to measure the CO_2-concentration in the corridors or in the staircase only. The central fans can be controlled via a Proportional-Integral controller (PI) to a set point of e.g. 600 ppm in order to keep high air quality in the staircase and corridor zone as a fresh air reservoir for ventilation of the class rooms. The concentration in the corridors will vary according to the occupation of the adjacent class rooms. Hence at least one CO_2-sensor per corridor should be installed.



O CO₂-concentration ● Room climate (T/RH)
● Light-sensor

Optimized monitoring system

In case of this simplified control strategy, only the flow rate of the central fans are controlled via the CO_2-sensor whereas the active overflow sensors in the class rooms are controlled via time schedule (on-signal one hour before the start of the lessons) and via presence control sensors (off-signal with 45 min. delay). The disadvantage of this strategy is a lower saving potential, if the number of pupils varies within a wide range, because the on/off-control will always provide the flow rate necessary for the maximum number of pupils.

The artificial light as well as the shading and daylight redirection lamellas is controlled via light-sensors on top of the roof and in the class rooms. A special BMS-system was installed especially for this purpose, enabling also an adaptive control of the colour-temperature of the artificial light according to the daylight. [2]

7.1.2 Percentage of the artificial light

Method:

The on / off logger will be mounted on the fluorescent lamp, in each of the selected classrooms. They collect and store using a light sensor to a light source on / off state. It can be determined how often, how long and at what times they are used. This provides insight in the general use of the lamps and hence the power consumption.

Meters:

_ Light On/Off Logger, product type Hobo U9-002 from the company onset: the internal light sensor monitors the on/off-status of fluorescent or incandescent lamps. The light sensitivity is peaked in the forward range and can be utilized to minimize the effect of other light sources when trying to determine the on/off state of a particular light source. The Light intensity threshold is adjustable from: 10 to 100 lumens/m2 [0.93 to 9.3 footcandles (lumens/ft2) (fluorescent light)]. For incandescent lamps the threshold is about ten times greater than above[3].

[2] 3encult Deliverable D4.2

[3] onset. (2010): product catalog 2010, page 14.

7.1.3 Determination of the daylight factor (Occasional)

Background:
The daylight factor is a measure of the day light feed into rooms. It consists of the ratio of illuminance Eint. at a point in the interior to the outside illumination $E_{ext.}$ of an unobstructed unshaded point. The daylight factor indicates what percentage of the external illumination passes through openings into a room. The factor is independent because of the proportionality of the light levels E_{int}. and E_{ext}. and due to the rotationally symmetric luminance distribution of sky covered by both the day and season and by the horizontal orientation of daylight openings and thus the building. Each point in a room has its own individual daylight factor.

The daylight factor is thus a geometrical parameter that depends on the following points:

• Room proportions (height, length, width);
• Skylight geometry (area, location, context and sprouts, shaft shape)
• Glazing material (transmittance, pollution) and the
• Reflectance of room surfaces and shafts[4].

Method:

To beable to calculate the daylight factor, two measurements are necessary. You need the illumination in the classroom and the illuminance at a nearby spot outside the building which is unshaded. This can be determined best on the roof of the building. It is important that the respective measurements are carried out almost simultaneously in order to achieve meaningful results. Therefore, for the measurement 2 persons are needed, which are in radio contact. One person measures the illuminance in the classroom with the sensor FLA603VL4 and the Almemo meter, while the other person simultaneously measures the illuminance on the roof.

Meters:
The following instruments are needed for the measurement of daylight factor:

_ Illuminance sensor FLA603VL4 of Ahlborn:
• 2 channels with different sensitivity (ambient light)
• Measuring range: 1 lux to 250,000 lux
• Minimum resolution: 1 lx
• Sensitivity: 20 pA / lx
• DIN class B
• Almemo cable
• approximated to photometric evaluation function V (λ) for photopic vision
• max. cos deviation: Class B, <3%
This sensor is used to determine the intensity of illumination in the room. Via a connecting cable the sensor is connected with the 2590-meter Almemo 4S. The meter records the range and the measured values automatically and stores them[5]

_Almemo Meter 2590-4S Ahlborn:
• 4 Almemo - jacks
• 59-KB EEPROM

[4] http://www.fvlr.de/tag_wasistlicht.htm.(17.12.2010)

[5] http://www.ahlborn.com/getfile.php?1295.pdf.(18.12.2010)

• LCD graphic display
• High-resolution A / D converter 16 bit, 10 measurements / s

The Almemo 2590-4S is a device for various measurements, depending on what sensor is installed. In this case it is possible to connect and manage four sensors simultaneously. When connecting a sensor each ALMEMO meter automatically displays the measurement range and the measured value. When changing the sensor on the device no need for adjustment is necessary. Each additional sensor is also automatically detected and the measured value is immediately displayed. The sensors can be changed even while the measurement is in progress. All the measurement values are stored by the Almemo 2590-4s and can later be fed to a PC for further processing and evaluation[6]

_Digitalluxmeter Minilux:
• Silicon photovoltaic cell
• Measuring range: 1 to 199 900 lx mlx
• Minimum resolution: 1 mlx
• DIN class B
• max. cos deviation: Class B, <3%
• approximated to photometric evaluation function V (λ) for photopic vision

The Digitalluxmeter Minilux is connected by one lead with a picture element and is used in our case for the measurement of the external illumination of the roof of the school[7].

7.1.4 Determination of the daylight profile

Method 1: coach with rail

To determine the exact course of daylight in a room it is necessary to define the daylight factor in lot a of different points. This measure is very manually intensive. You can manage this by using a on rails mounted coach on which you attach the illuminance sensor. The sensor must record at the height of the working plane. The car is pulled from one to the other end of the room. During that process the measuring sensor detects and stors the light intensity for example every 50 cm. Out of this information a daylight profile can be generated. In the next step the rail is moved in a parallel position. The process is repeated to create enough profiles to have sufficient information to build up a surface of the daylight factor. At the same time the illuminace has to be measured on the roof for each point.

In this method the same instruments are used as in the method that is described in point "1.2 Determination of the daylight factor (Occasional)".

Method 2: Photo Analysis

Another method to determine the daylight factor grid in a room is possible with the application of the visualization program VIVALDI[8]. The principle of this measurement is to get the luminance of the surfaces of a HDR picture. So it is possible to calculate the illuminance of diffuse reflective surfaces in different points. As soon as the internal illuminace in every point of the picture is the rest of the process to get the daylight factor is similar to the method that is described in point "1.2 Determination of the daylight factor (Occasional)".

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[6] http://www.ahlborn.com/getfile.php?1059.pdf.(18.12.2010)

[7] http://www.mx-electronic.com/english/preisliste.htm. (15.12.2010)

[8] Software by Zumtobel

The following steps describe this process more detailed:

Step 1: Select a suitable position from which to photograph the room.

Step 2: To receive photos suitable for creating HDR files a number of various camera setting are needed:

• Image Recording Quality: RAW (1024-16384 brightness gradations)

• Set the camera to aperture priority Av

• Select a low ISO (100 ISO)

• Flash off

• Setting the mode batch image

• Place the camera at exposure AEB (automatically makes 3 shots with different exposures: under-, normal and overexposed)

• set exposure increment of + / -2 EV[9]

Important is the use of a tripod (to avoid vibrations) and a wide-angle lens.

Step 3: Create an HDR file from the three shots with different exposures by software (e.g. Photomatix Pro 4). The program calculates a image with increased dynamic range. The result is a HDR file, which is a prerequisite for working with VIVALDI.

Step 4: Determination of the luminance at a particular point in space. The luminance measurement is attributed to a light intensity measurement with a known solid angle. To measure the luminance, a tube is mounted on the photo meter head (element, which when illuminated produces electric. voltage). If you focus now with the sensor on a surface, it measures the illuminace of that surface. This value multiplied by the factor 100 is the luminance of the surface (the geometry of the tube is calculated so that the relationship between luminance and illuminance is well known). The final result is the average luminance of the elected surface in cd/m².[10].

Step 5: Editing with Vivaldi (Visualization Software). Once the program calibrates the luminance calculated in step 4 at one point, the luminance values in all other points on the photo can be calculated. From that the light intensity distribution in space can be derived.

In this research project we will apply both methods. Method 1 will be necessary to control method 2.

Meters for Method 2:
_ Canon EOS 400D:
• Digital AF / AE SLR
• High sensitivity, high resolution CMOS sensor
• Ca. 10,10 Megapixel
• Image sensor size: 22.2 x 14.8 mm

[9] http://www.hdrsoft.com/de/support/PhotomatixProManualde.pdf (15.12.2010)

[10] http://www.mx-electronic.com/pdf/Bedienungsanleitungdeu.PDF (15.12.2010)

• Image type: JPEG, RAW (12 bit) [11]

_ Digitalluxmeter Minilux with attached tube:
see "2.1.2 Determination of the daylight factor (Occasional)".

7.1.5 Comfort Measurment

The comfort is a human sensation, which is influenced by parameters from the environment. Comfort is a combination of physiological, psychological, sociological and aesthetic influences.

Method:
The measuring arrangement allows the measurement of physical parameters for the assessment and evaluation of thermal comfort in 3 heights simultaneously. Thus the assessment of heating and ventilation systems is achieved. The following sensors are used for the measurement:

• Combined humidity and temperature sensor
• NTC – sensor (thermistors)
• Globe thermometer
• Thermo-anemometer

In addition to the series of measurements you need another input parameters such as clothing factor, activity level and mechanical power to work with the AMR Win Control. With this software it is possible then to calculate the PMV and PPD values according to EN ISO 7730 as well as determine the degree of turbulence according to DIN 1946 Part-2[12].
The PMV-value is the average estimate (from 3 hot cold to -3) of the indoor climate. It can then determine the PPD value. This meant the percentage of dissatisfied[13]..
The degree of turbulence is a number with which the quality of a flow can be described[14].
Wikipedia: "turbulence". URL: http://de.wikipedia.org/wiki/Turbulenzgrad

Meters:
_Humidity + temperature sensor combination of FHA646E1 Ahlborn[15].:
Humidity Measuring Circuit:
• Measuring range: 0 ... 100% r.H.
• Sensor: capacitive
• Accuracy: ± 2% r.H. in <90% r.H.
Temperature-measuring circuit:
• Sensor: NTC type N
• Accuracy: -20 ... 0 ° C: ± 0.4 ° C, 0 ... 70 ° C: ± 0.1 ° C, 70 ... 80 ° C: ± 0.6 °

Capacitive sensors work based on the change in the capacity of a single capacitor. Furthermore, the sensor has a

[11] http://www3.canon.de/images/pro/fot/slr/geh/file/EOS_400D_HWG_deu.pdf (18.12.2010)

[12] http://www.ahlborn.com/getfile.php?1281.pdf (18.12.2010)

[13] Keller L. (2009): "Guidelines for ventilation and air conditioning systems. Industry Oldenbourg Verlag

[14] http://de.wikipedia.org/wiki/Turbulenzgrad

[15] http://www.ahlborn.com/getfile.php?1206.pdf (18.12.2010)

built-in NTC sensor. This refers to a resistance with negative temperature coefficient, i.e. with increasing temperature the resistance of a building element drop off[16]..

_NTC - sensor (thermistors) of FNA 20L0100 Ahlborn[17]:
• Accuracy: -20 ... 0 ° C: ± 0.4 ° C, 0 ... 70 ° C: ± 0.1 ° C, 70 ... 80 ° C: ± 0.6 °
This sensor is approximately set at ankle height.

_Globe thermometer FPA805GTS of Ahlborn[18]:
• Accuracy: Class B (DIN / IEC 751)
• Sensor: Pt100 4-wire, arranged in the center
The globe thermometer detects thermal radiation load.

Thermo-anemometer FVA605TA1OU of Ahlborn[19]:
• Measuring range: 0.01 to 1 m / s
• resolution 0.001 m / s
• Accuracy: ± 1.0% FS and ± 1.5% of reading
Small flow rates are measurable with the Thermo-anemometer.

7.1.6 Carbon dioxide measurement

The CO2 concentration in a room is a good assessment parameter for air quality, because it is a indicator for the emission of organic vapors by humans. There is also a direct connection to the use intensity of space. Poorly ventilated areas can lead to mood disorders, such as fatigue, poor concentration and so on. Besides the people can also pollutants from building materials and furniture, or fine dust, downgrade the indoor air quality[20].

Method
The CO2 content of air is measured by using a hand probe.

Meters:
_Almemo meter 2590-4S Ahlborn:

_Carbon dioxide sensor FYA600CO2H of Ahlborn:
• Sensor: 2-channel infrared with principle of absorption
• Range: 0 .. 10000 ppm (0 .. 1 vol% CO2)
• Accuracy: ± 0 .. 5000 ppm (50 ppm + 2% v.M.)
• Resolution: 1 ppm or 0.0001% by volume[21]

[16] http://www.gutefrage.net/frage/was-ist-ein-ntc-sensor (20.12.2010)

[17] http://www.ahlborn.com/getfile.php?1186.pdf (16.12.2010)

[18] http://www.ahlborn.com/getfile.php?1281.pdf (16.12.2010)

[19] http://www.ahlborn.com/getfile.php?1234.pdf (16.12.2010)

[20] Passive House Institute (2010): Guidelines for energy-efficient education building.

[21] http://www.ahlborn.com/getfile.php?1313.pdf (14.12.2010)

7.2 Monitoring system after intervention

7.2.1 General description

The interventions are still in progress.

In the case after refurbishment the monitoring system has been modified. During this second monitoring phase, the files format is .dat where the values are separated by spaces. Nevertheless, that is not a standard; therefore, a treatment before storing the data is needed. In this case, the spaces have been replaced by semicolon. Afterwards, it is necessary to know the meaning of every field. Table 7 summarises the meaning of the data stream for the first 12 data-points (up to 88), being a similar system than the CS8 one. It is displayed the device (measuring group), the channels of the device, the device connected to the channel, the position of the sensor and the data-point number.

Measuring group	Channel	Device	Kind of sensor	Sensor position	Value number
R2a AB01 329	A1	0_0	ST	Classroom 011 comfort level	0
	A2	0_1	ST	Classroom 012 comfort level	1
	A3	0_2	ST	Classroom 111 comfort level	2
	A4	0_3	ST	Classroom 214 comfort level	3
	A5	1_0	AT	Classroom 011 comfort level	4
	A6	1_1	AH	Classroom 011 comfort level	5
	A7	1_2	AT	Classroom 012 comfort level	6
	A8	1_3	AH	Classroom 012 comfort level	7
	A9	2_0	AT	Classroom 111 comfort level	8
	A10	2_1	AH	Classroom 111 comfort level	9
	A11	2_2	ST	Classroom 209 comfort level	10
	A12	2_3	ST	Classroom 209 comfort level	11

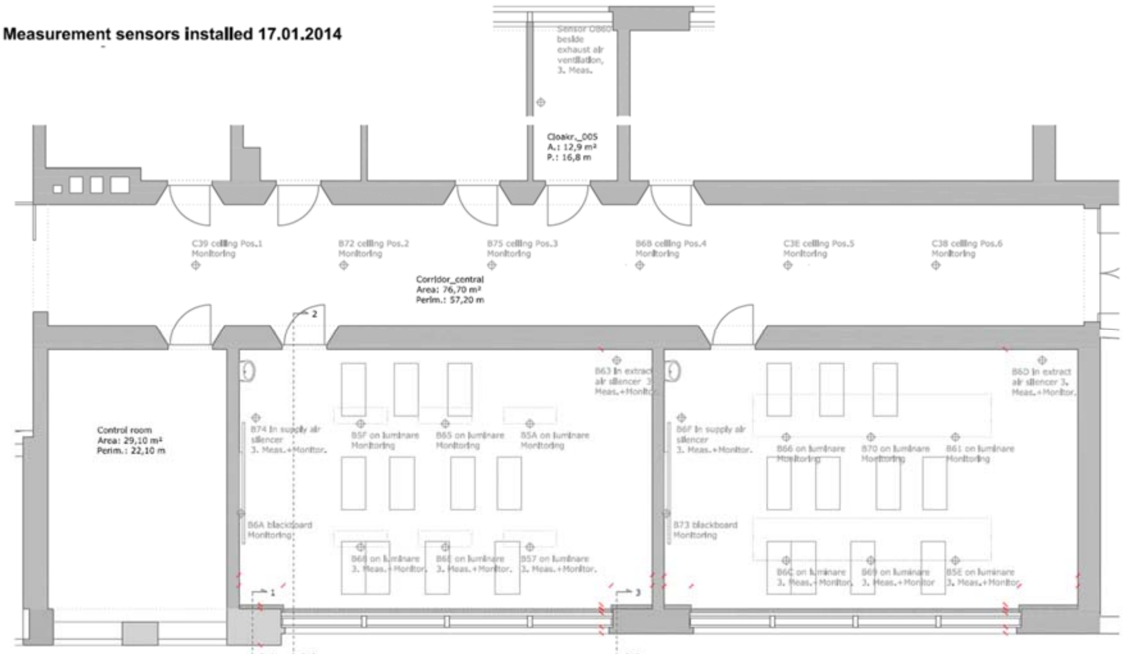
Table 7: CS5 after refurbishment data example [22]

[22] 3encult Deliverable D4.4

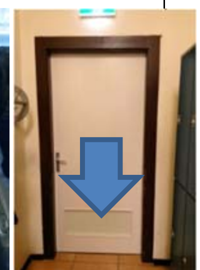
7.2.2 Measuring system (planning shows the position of the sensor)

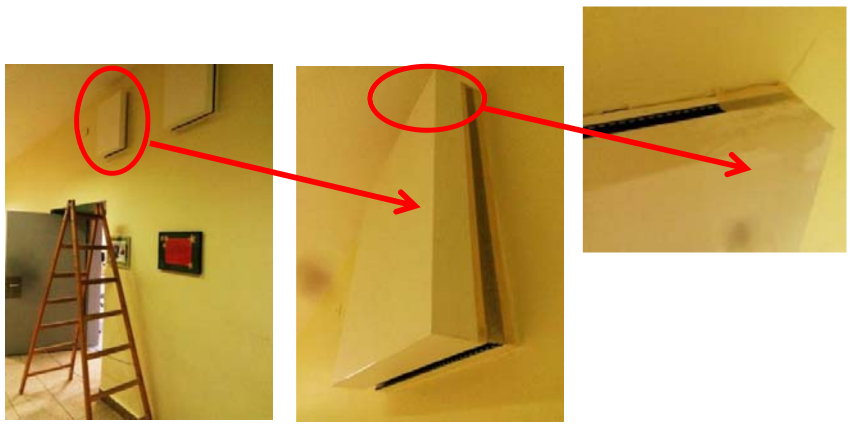
7.2.3 Monitoring scheme (data logger)

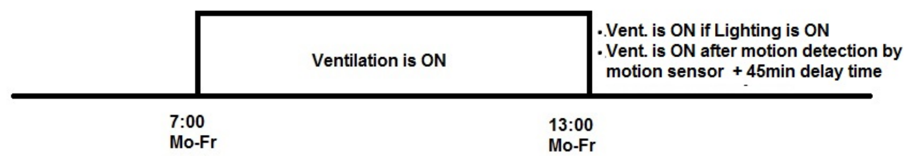
7.2.4 Measuring Sections



Date	Time	Adjustment

20.11.2013	08:30	Increase the flowrate of exhaust fan (0B60) from 133 to 146 Now the force to open the door is already on a level that small children could have problems to open the doors due to the suction of the fan. The area of the grill on the door should be enlarged. Rainer will be asked how to proceed?   
05.12.2013	17:30	The sensor 0B60 was moved from the exhaust fan casing to the place close to the ceiling within the same room, because there were some suspicion that the ventilator sucks inside some additional air through the untight windows frame. That would explain the low CO2 concentration measured in exhaust fan casing. 

05.12.2013	17:30	The flow rate of the supply fans in both classes was increase the to level 550 m3/h.  Class room 1. Voltage 8.74V  Class room 2. Voltage 9V Side and part of the upper corner of the intake cover-plate in the corridor were sealed with tape to prevent suction of the waste from class r. 2 to air supply of class room 1 
16.12.2014		Teacher manually switch off the ventilation unit in class room 1. The CO2 concentratin rised up from peakes of (supply 800ppm / exhaust 1300ppm) to peakes of (2300ppm). Othervise the offset of supply/exhaust is about 100/150ppm what indicates really good mixing.
17.01.2014		 Window in the man´s toilet was opened and the door as well.
17.01.2014		Class room 1, 2 – motion sensor can have longer extension time, when nobody moves it goes off very fast

<table>
<tr><td>17.01.2014</td><td></td><td>The flow rate of the supply fans in both classes was decreased to 450m3 per h
<table>
<tr><td></td><td>450 m3/h</td><td>550 m3/h</td></tr>
<tr><td>Class room 1</td><td>7,9 V</td><td>8,77 V</td></tr>
<tr><td>Class room 2</td><td>8,2 V</td><td>9,05 V</td></tr>
</table></td></tr>
<tr><td>17.01.2014</td><td></td><td>The ventilation unit in Class room 1 was OFF (manually by teacher) when we came on 17.01.2014</td></tr>
<tr><td>30.01.2014</td><td></td><td>Person from Zumtobel came to Hottinger school and re-set the central computer</td></tr>
<tr><td></td><td></td><td>Person from Zumtobel came to Hottinger school and re-set the central computer, put new setting for Ventilation control: controlled by lighting by motion sensor and is permanently ON between 7-13, correct</td></tr>
<tr><td></td><td></td><td>
</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>21.03.2014</td><td>15:00</td><td>The ventilation unit in Class room 1 was OFF (manually by teacher) when we came on 21.03.2014</td></tr>
<tr><td>21.03.2014</td><td>15:00</td><td>The time delay of ventilation as 4-5 min only!!!</td></tr>
<tr><td>21.03.2014</td><td>15:00</td><td>Doors and Window in the man´s toilet was opened and the door as well.</td></tr>
<tr><td>21.03.2014</td><td>15:00</td><td>Data was downloaded and the 25 sensors were removed from Hottinger school</td></tr>
<tr><td>21.03.2014</td><td>15:00</td><td>Sensor C38 seems to be broken</td></tr>
</table>

7.2.5 Sensor details

Measuring sensor used for monitoring of indoor climate and indoor air quality.

HUMLOG 20, E+E

The HUMLOG 20 is a wall mount unit for architectural spaces monitoring temperature and humidity with new versions for barometric pressure or CO2 as a third parameter. It is intended as a stand alone monitor/ logger to replace mechanical thermohygrograph devices. It is more accurate and reliable and will store virtually unlimited data. The software, SmartGraph 3, is for set up and download and analysis of data with ethernet network capability as standard.

Stores 3.2million values - 16 Mb

Accuracy +/- 0.3C and +/- 2% RH, +/-0.5hPa, 50ppm +/-3% of reading CO2

External sensor for RH/T or for temperature only (2)

Displays RH/T, and CO2 or Barometric and relative air pressure - 3 different models

Ethernet and USB interface included

SmartGraph 3 PC software - export data, printout, administration for 255 loggers

Battery life 12 months - 4 months for TCO - optional POE (power over ethernet)

The units have standard display and includes visual, and acoustic alarm with simple one button operation. USB and ethernet ports are included.

8 Annex 3 - Case Study organisation

8.1 Local Case Study Teams (LCS teams)

Case study leader/ 3ENCULT responsible partner:

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8.2 Annex 4 – Blower-door test report

Please see files “20110620_PB_EN 13829_HS Hoetting.pdf” and “2011-04-28 PHPP2007.pdf” attached in the same folder as this report.