D8.9 Educational Material for University Studies

Sustainable Refurbishing of Historic Buildings and Relevant Building Physical Aspects based on

Case Study 5: Secondary School Hötting
Innsbruck, Austria

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Guiding principle

Presentation 1
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Partner: University of Innsbruck (UIBK)
University course: Nachhaltige Gebäudesanierung ("Sustainable Renovation" for Students in "Masterstudium Domotronik")
Date: 16.01.2013
Place: Innsbruck, University of Innsbruck, SR-Container 5
Title of the lesson: “Sustainable Renovation of Buildings - Lessons learnt from 3ENCULT-Case Study CS5”
Description of the contents: Within the university course "Sustainable renovation", students learn refurbishing strategies and how to include energy efficiency. The course "Nachhaltige Gebäudesanierung" is about refurbishing in general (not only on listed buildings and cultural heritage), however the training material elaborated within 3ENCULT has it's special focus on that. The content includes some introduction in terms of basic building physical issues as well as the principles of conservation. The school building CS5 (NMS Hötting) was used to demonstrate how to find well adapted solutions for a specific building, based on detailed building diagnosis and measuring results for comfort and air quality parameters.
Name of the file: WP8_D8.9_20131007_UIBK-Presentation 1
Basic principles
- Conservation principles
- Building physical principles

Case study example 3ENCULT CS5
- Building diagnosis and comfort measurements
- Minimal invasive insulation
- Prevention of condensation Optimization of heating control
- Development of new ventilation concept
- Enhanced daylight autonomy by daylight redirection
- Improved artificial lighting using LED
- Highly efficient acoustic absorbers
Conservation Principles

Introduction

- “Historic structures constitute a large percentage of the building stock in Europe and a valuable asset for residential, public, representative cultural and touristic use. Although usually legally treated as exceptional cases and thus excepted from energy legislation, energy efficiency is a good chance to support the future use of historic buildings. Through smart implementation of high quality energy efficiency solutions in many cases a notable reduction in the energy demand of historic buildings is achievable. However, working on historic buildings requires sensitive approaches.”

Source: D3.3 Introduction (Christoph Franzen (IDK), Torben Dahl (KA), Ola Wedebrunn (KA), Franziska Haas (TUD))
The Basic Principles of Cultural Heritage Preservation

- **Preservation** of the building
- **Retaining** the historic character
- **Maintaining** the structure

Any intervention has to avoid or minimize the

- **Impact on** substance (material)
- **Impact on** image

If changes are not avoidable, the interventions should guarantee the reversibility.
Conservation Principles

Basic questions to be answered before any intervention in historic buildings

- What kind of, which amount and where is destructive work on the building needed for that implementation?
- What is the change of the actual appearance?
- What is the change in terms of the historic use and architectural idea?
- What are the consequences for the total building climate?
- How is made sure, that the new climate situation does not risk the building material or the interior?

Source: D3.3 Introduction (Christoph Franzen (IDK), Torben Dahl (KA), Ola Wedebrunn (KA), Franziska Haas (TUD))
Cultural Heritage: EIA, SEA and SUIT

Wind tunnel, Hispano-Suiza, Bois Colombes: 1937-1999
Historic monument

Source: Gerald Gaigg, case study group CS5
Cultural Heritage: EIA, SEA and SUIT

Soufflerie Hispano-Szuiza, Bois Colombes: 1937-1999
Historic monument
Conservation Principles

Further Reading

- **D2.1** Report on demand analysis and historic building classification
- **D2.2** Position Paper on criteria regarding the assessment of energy efficiency measures regarding their compatibility with conservation issues
- **D2.5** Report on Methodology and Checklist

Source: D3.3 Introduction (Christoph Franzen (IDK), Torben Dahl (KA), Ola Wedebrunn (KA), Franziska Haas (TUD))
Building Physical Principles

Energy Efficiency - Basic Principles

- Reduction of transmission losses
- Reduction of ventilation losses
- Avoiding of thermal bridges, condensation and mold
- Passive solutions: Building envelope and thermal inertia
- Active solutions: Energy efficient heating, cooling and building services

Source: D3.3
CS 5   NMS Hötting
Located in Innsbruck, Austria
Construction in 1929/30, architects Franz Baumann & Theodor Prachensky

One of the most **important examples** of early modern architecture in Tyrol (Peter Behrens style), listed!

Annex from 1950 at the northeast part of the building

Still in use as **school for pupil** at the age of 10 up to 15
Problems, which had to be solved:

- **High heating** energy demand ± 130 kWh/(m²a)

- **Summer overheating** problems due to large unshaded glazing areas

- **Air quality** problems and low **thermal comfort**
  
  *draft risk and low surface temperatures in winter*
Cultural Heritage: EIA, SEA and SUIT
Why building diagnosis?

- Documentation of damages and risk of damages of the building construction
- Lack of comfort
- Information for decisions on future interventions

What kind of building diagnosis?

- Thermal, visual and acoustic comfort, indoor air quality
- Thermal bridges
- Material tests (plaster, screed, concrete, iron)
Thermal comfort
- Draft risk (air velocity)
- Temperature (radiation and air temperature)
- Relative humidity
- Open/close Status of windows and doors

Visual comfort
- Artificial light situation
- Daylight situation

Indoor air quality
- high ventilation heat losses because of long-term windows ventilation even in winter
Analysis of Energy Demand

- 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
Energy consumption of the electric lighting

-> Percentage of the artificial lights is monitored by on/off logger which are mounted at the luminaires
3 Sensors at the same height (1m above floor level):

- Combined humidity and temperature sensor
- Globe thermometer for radiative temperature
- Thermoanemometer for indoor air velocity (draft risk, turbulence of air)

1 NTC – sensor for temperature 10 cm above floor level

All sensors are logged by the Almemo logger 2590-4S

-> Calculation of the PMV and the PPD values
Window Ventilation

The indoor climate is influenced by the users and their manual ventilation behavior.

-&gt; therefore open/close loggers with reed contacts are mounted at the windows.
Measurement of the indoor air CO2 concentration at the same altitude (1m above floor level)

-> the occupancy of the rooms is important for both measurements: indoor air quality and thermal comfort

<table>
<thead>
<tr>
<th>Classification (DIN EN 13779)</th>
<th>Description</th>
<th>CO₂-concentration above external concentration [ppm]</th>
</tr>
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<tbody>
<tr>
<td>IDA 1</td>
<td>high indoor air quality</td>
<td>&lt; 400</td>
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<tr>
<td>IDA 2</td>
<td>mean indoor air quality</td>
<td>400 - 600</td>
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<td>IDA 3</td>
<td>moderate indoor air quality</td>
<td>600 - 1000</td>
</tr>
<tr>
<td>IDA 4</td>
<td>low indoor air quality</td>
<td>&gt; 1000</td>
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### Occupancy of the classrooms

<table>
<thead>
<tr>
<th>Klasse 1a - 011</th>
<th>Klasse 3b - 111</th>
<th>Klasse 2a - 114</th>
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</thead>
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<td>Mo</td>
<td>Di</td>
</tr>
<tr>
<td>1</td>
<td>07:45</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>08:40</td>
<td>09:30</td>
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<tr>
<td>3</td>
<td>09:35</td>
<td>10:25</td>
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<tr>
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### Klasse 3b - 201

<table>
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<th>Klasse 3c - 214</th>
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</tbody>
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### Klasse 3c - 214

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<th>Klasse 3b - 111</th>
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</thead>
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<td>10</td>
<td>15:50</td>
<td>16:40</td>
</tr>
</tbody>
</table>
Method 1:   -> Measurement of the illuminance at the height of the working plane in a grid of ca. 90*90cm inside the room

   -> Measurement of the illuminance at a unobstructed point (at the roof) at the same time

   -> Calculation of the daylight factor
Daylight Measurement

Daylightfactor room 010

Daylight [%]

- 2,50-3,00
- 2,00-2,50
- 1,50-2,00
- 1,00-1,50
- 0,50-1,00
- 0,00-0,50
Method 2 -> Measurement of the illuminance in- and outside, measuring of the luminance and taking pictures with a digital camera at the same time

-> Creation of a HDR-file out of the pictures

-> Definition of the luminance at one spot

-> Calculation of the factor
Glare

- Taking 5 pictures with a calibrated digital camera in defined directions
- Creation of a HDR-picture out of these pictures (WEB-HDR)
- Readout of the luminance and definition of the areas with glare risks
Possible Reduction of Heat Demand

Transmission heat losses:
- Windows
- External wall
- Floor slap
- Last ceiling

Ventilation heat losses:
- Windows

Annual heat demand [kWh/(m²a)]
Possible reduction [kWh/(m²a)]

Status quo: 129 kWh/(m²a)
Transmission heat losses:
- Windows: 14 kWh/(m²a)
- External wall: 28 kWh/(m²a)
- Floor slap: 52 kWh/(m²a)
- Last ceiling: 58 kWh/(m²a)
- Ventilation: 96 kWh/(m²a)

Possible reduction: 75%
Energy Efficient Solutions

- Development of new **ventilation concept** Prevention of condensation at **beam end** of the concrete brick ceiling (internal insulation)
- Enhanced **daylight autonomy** by daylight redirection
- Improved **artificial lighting using LED**
- Optimization of **heating control**
- Minimal invasive **external insulation**
- Different variants of **internal insulation**
- Highly efficient **acoustic absorbers**

Relative humidity [%] at beam end

Max: 86.357

85
80
75
70
65
60
55
50
Min: 46.299
Box-type windows
Box-type windows improvements:
Classroom 1

**mounting:** airtightness, thermal bridges
**heatflux:** double glazing

\[ U_w \, 1.1 \, \text{W/m}^2\text{K} \text{ (before } U_w \, 2.8 \, \text{W/m}^2\text{K) } \]
IR-Thermography after intervention (prototype classrooms)

3ENCULT CS5, Höttinger School
**Interior insulation:** Remmers IQ Therm 80

Reversibel (loam glue)

Thermal conductivity **0,033 W/mK, capillaryactive***

*PUR-foamboards with capillaryactive calcium silicate - wicks*
**Interior insulation:** Wegscheider Holzbau / Isocell

Reversibel: wooden frame construction, loam plaster, cellulose

Thermal conductivity: **0,04 W/mK**, **capillaryactiv** cellulose
CS 5
NMS Hötting
Interventions on exterior wall

**Interior insulation:** Wegscheider Holzbau / Isocell
Radiators: heating water temperature actually up to 85°C

Target: lowering temperature to a level of 45°C integrating RE (solar thermal collectors)
Central system with direct vertical supply air ducts
Principle of Active Overflow in school buildings
Pros and Cons of Active Overflow

- Minimized duct network
- Low impact for historic buildings
- Easy control system
- Mixed air in corridors
- Fire protection doors have to be kept open
Decentralized wall integrated ventilation system

- Supply air inlet
- Radiator
- Ambient air
- Filter
- Silencer
- Heat exchanger
- Extract air outlet
- Supply air
- Exhaust air
- Perforated plate
- Slit below the window sill
Central ventilation unit with heat recovery at the attic
Separated unit for groundfloor (kitchen and working spaces)
CS 5
Two prototype classrooms
Fresh air over main staircase & passages, exhaust air passing by toilets and wardrobes
Textile diffusor

Fan

Silencer

Önorm B 8115-2 (Normalized sound level difference).

$L_{p,A,nT}$ max 35 dB

Class room

Corridor

$R_w 38$ dB. $R_w$ door min 28 dB
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Wall breakthrough for the silencer
CS 5 NMS Hötting
Active Overflow elements

Sound absorber plate

Silencers
CS 5
Active Overflow elements

NMS Hötting

Fan box

Round silencer
CS 5
Passive overflow element with silencer

NMS Hötting

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Sound absorber plate

Passive overflow element with silencer
Textile diffusor
(Prihoda, CZ)

Laser perforation    Flow visualisation    Snemometer measurement of air flow velocity

(Source: Prihoda, CZ)
Mounting of textile diffusor
Finished ventilation system: Supply air through textile hose

Function of textile hose:
- distribution of air evenly
- covering of silencer
- reduced maintenance
CS 5
NMS Hötting
Test Setup: Exhaust Air Fan

Exhaust air

Fresh air over staircase, passages
Control of central and active overflow fans

Central fan control by CO₂

Active overflow fan control:
- **On** by time schedule
- **Off** by presence sensors in class rooms
CO$_2$-Simulation Results (CONTAM-Simulation)

![Graph showing CO$_2$ concentration over time with different lines for Staircase, Corridor, Classroom 1, and Classroom 2. The graph includes a horizontal line at 1000 ppm.](image-url)
Measurement of CO$_2$-concentration at different positions and levels in the classroom and corridor
Sensor Positions for CO₂-Concentration Measurement
- 2 windows opened for about 8 minutes (left arrow)
- Pupils are not in classroom the first 15 minutes of the lesson (right arrow)
Measured Pressure Drop at the Textile Diffusors

- Pressure diff. diffusor [Pa]
- Flow rate [m³/h]

- Classroom 1
- Classroom 2
Results of noise-level measurement as function of the flow rate

Noise level of active overflow system $L_{p,a,nT}$ at $T_0 = 1.0 \text{ s}$

Flow rate [m$^3$/h]
Result: The quality of the protection for airborne sound transmission according to ÖISSL was achieved.

class room 1: 41 dB
class room 2: 42 dB

According to ISO 717-1
\[ D_{nT,w(C;Ctr)} = 41 (0; -2) \text{ dB} \]
Three solutions for minimal invasive ventilation systems (decentral, central, vertical and active overflow)

Active overflow ventilations for school building realized (prototype by ATREA) and measured

Good sound protection from class room to corridor (41 dB)

High electric efficiency (0.09 Wh/m³)

On/Off control by time schedule and presence sensors

Draft free supply air inlet by textile diffusors
Details and daylight
Classroom 1:
- LED lighting
- Automatic dynamic artificial and daylight control
- High-end solution (colour temperature control)

Classroom 2:
- Artificial light by fluorescent lamp
- Energy efficient daylight dependant control
- Light integrated in sound absorber
Classroom 1:
- Control element
## Before Intervention

### Classroom 1

<table>
<thead>
<tr>
<th></th>
<th>Window</th>
<th>Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area</td>
<td>64,5</td>
<td>64,5</td>
</tr>
<tr>
<td>Occupied time in monitoring period [h]</td>
<td>826</td>
<td>826</td>
</tr>
<tr>
<td>Operation time per year[h]</td>
<td>513,68</td>
<td>528,43</td>
</tr>
<tr>
<td>Electric power consumption [W]</td>
<td>266,8</td>
<td>266,8</td>
</tr>
<tr>
<td>Elektric energy [kWh]</td>
<td>137,05</td>
<td>140,99</td>
</tr>
<tr>
<td>Energy consumption [kWh/m²a]</td>
<td><strong>4,31</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Classroom 2

<table>
<thead>
<tr>
<th></th>
<th>Window</th>
<th>Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area</td>
<td>64,5</td>
<td>64,5</td>
</tr>
<tr>
<td>Occupied time in monitoring period [h]</td>
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<tr>
<td>Operation time per year[h]</td>
<td>650,2</td>
<td>654,35</td>
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<tr>
<td>Electric power consumption [W]</td>
<td>266,8</td>
<td>266,8</td>
</tr>
<tr>
<td>Elektric energy [kWh]</td>
<td>173,47</td>
<td>174,58</td>
</tr>
<tr>
<td>Energy consumption [kWh/m²a]</td>
<td><strong>5,40</strong></td>
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</table>
## After Intervention

### Classroom 1

<table>
<thead>
<tr>
<th>Lights:</th>
<th>Window</th>
<th>Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface area</td>
<td>64,5</td>
<td>64,5</td>
</tr>
<tr>
<td>Occupied time in monitoring period [h]</td>
<td>826</td>
<td>826</td>
</tr>
<tr>
<td>Operation time per year[h]</td>
<td>513,68</td>
<td>528,43</td>
</tr>
<tr>
<td>Electric power consumption [W]</td>
<td>279,5</td>
<td>279,5</td>
</tr>
<tr>
<td>Saving by daylight dependent control</td>
<td>0,52</td>
<td>0,74</td>
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<tr>
<td>Electric energy[kWh]</td>
<td>102,89</td>
<td>125,02</td>
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<tr>
<td>Energy consumption [kWh/m²a]</td>
<td><strong>3,53</strong></td>
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### Classroom 2

<table>
<thead>
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<th>Window</th>
<th>Wall</th>
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<td>Electric power consumption [W]</td>
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<td>Saving by daylight dependent control</td>
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<td>Electric energy[kWh]</td>
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<td>Energy consumption [kWh/m²a]</td>
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Comparison of consumption before and after Intervention

<table>
<thead>
<tr>
<th>Classroom 1</th>
<th>Classroom 2</th>
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<tbody>
<tr>
<td><strong>Energy consumption old [kWh/m²a]</strong></td>
<td><strong>Energy consumption old [kWh/m²a]</strong></td>
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<td>4.31</td>
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<td><strong>Energy consumption new [kWh/m²a]</strong></td>
<td><strong>Energy consumption new [kWh/m²a]</strong></td>
</tr>
<tr>
<td>3.53</td>
<td>3.98</td>
</tr>
</tbody>
</table>

- Classroom 1: 18% reduction
- Classroom 2: 26% reduction
**Classroom 1:**
- Combined system for day light redirection and shading

Day light redirection

Shading

Type E 80 LD
Project partners:

3ENCULT (project coordination EURAC, Bozen, IT)
- **building physics, measurements**: Uni Innsbruck, Uni Stuttgart, Cartif, PHI
- **thermography**: IDK Institut für Diagnostik und Konservierung an Denkmalen
- **daylight/shading**: Bartenbach Lichtlabor
- **PV**: Soliker
- **interior insulation**: Remmers
- **ventilation**: Atrea

Others
- **artificial lighting**: Zumtobel, Tridonic
- **daylight/shading**: Warema
- **interior insulation**: Holzbau Wegscheider, Isocell
- **acoustic absorbers**: Organoid Technologies
- **cultural heritage authority**: BDA