DEVELOPMENT OF NEW SYSTEMS AND TECHNOLOGIES FOR SUSTAINABLE REFURBISHMENT OF EUROPE'S BUILT HERITAGE

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ABSTRACT

Historic buildings are a living symbol of Europe's rich cultural heritage and reflect society's identity. Yet, this is an area where the high level of energy inefficiency is contributing to a huge percentage of greenhouse gas emissions. Climate change poses a real and urgent threat to humanity and its surroundings. Hence it is necessary to guide an improved approach to all refurbishment actions in historic buildings. In this paper the sustainable refurbishment of Europe's built heritage is improved through the development of new systems and technologies both for "hard facts" energy efficient building concept and "soft systems", such as the intelligent monitoring & control system. This approach is also reflected in the application of this system at eight practical case studies.

Keywords

Interior insulation, hygrothermal simulation, moisture adaptive vapor barrier, historic building construction, condensation, diffusion-open, capillary active, Wireless sensor, smart phones, smart window.

1. Introduction

A wide range of perspectives is offered by the opportunity to improve thermal standards of historically listed building through new technologies and at the same time increase thermal comfort. On the one hand, thermal renovation contributes in a significant way to achieve the Kyoto-target. On the other hand, energy efficiency leads to an increase of thermal comfort and therefore to an increase in the values of historical buildings, and the attractiveness of the living environment will increase as well. Energy efficient design offers in many cases the only appropriate way to improve hygrothermal standards.

The activities in this research are accompanied and stimulated by the involvement of eight case studies. At the same time, the different case studies will allow the assessment of the developed solutions. From here an analysis will be conducted to generalize the found solutions, identify replicable factors and the context where replication is possible. The case studies were chosen in order to represent different climatic conditions, utilizations, epochs and degree of conservation restrictions, needed/planned interventions and different time schedule of implementation. The case studies are: Public Weigh House in Bozen, Palazzo d'Accursio, Bologna, Palazzina della Viola Bologna scan, The Material Court of the Fortress, Copenhagen, Monumental School – Innsbruck, Warehouse City Potsdam and other, Industrial Engineering School in Salamanca and Strickbau Appenzell in Switzerland. At these eight case studies we implemented and tested the analysis and diagnosis procedures, the developed energy efficiency solutions and the integrated monitoring & control concept in order to carry out the developed system and technologies. The solutions used in the case studies are generalized both theoretical and experimentally [1].

2. New building technology used at the case studies

New building systems and technologies developed within the project are demonstrated by the case studies, comprising in intelligent monitoring and control system and energy efficient building concept as well. Selected specific solutions are presented below

2.1 Thermal insulation systems for internal insulation

The use of interior insulation systems has been structurally studied for over 20 years in the course of attempted thermal renovation of our monuments. In this context, particular attention is given to the expected moisture accumulation in the walls' cross section. There are two principal possibilities to confront this moisture problem depending on the way internal insulation is executed:

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- Diffusion tight interior insulation systems:

Using this type of Insulation system, the vapor diffusion flux into the wall is disabled. Vapor barrier-foils, moisture dense interior plaster, or approximate diffusion-proofed insulating foams are used. As a positive result, the condensation within the structural element can be avoided, if the barriers are kept working. Disadvantageous is the circumstance, that existing moisture in the construction is tapped and may damage e.g. wooden beam heads. Penetrating wind-driven rain lead to equivalent damages.

- Diffusion-open, capillary-active interior insulation systems

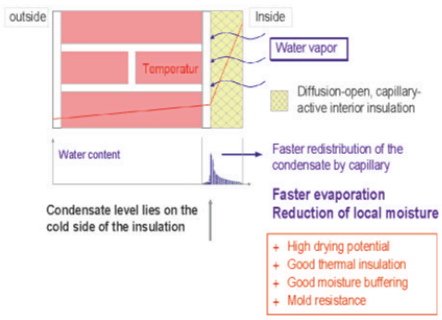

Abbildung 1. Wirkprinzip der kapillaraktiven

Figure 1 Operating principle of capillary- active inner insulation

These systems allow vapor diffusion into the walls, buffer the resulting moisture and remove the liquefaction from the condensation zone back inside. The moisture load of the wall is therefore considerably reduced. The hygroscopic storage capacity of a diffusion-open, capillary-active interior insulation system buffers humidity peaks of indoor air and regulates the indoor climate. The capillary action ensures that moisture is distributed rapidly and widely inside the insulation during the winter period. This accelerates the drying process and improves the effect of the insulation. Crucial for the functioning and performance of the internal insulation is the interplay between moisture buffering, vapor and liquid water transport. Moisture is buffered and transported in the hygroscopic and also in the over-hygroscopic range. Therefore, an assessment of internal insulation requires the exact knowledge of these variables and needs more sophisticated measurements than usual. The following figure 1 shows the principle of capillary-active inner insulation [2].

At the point where the dew point is reached, water vapor condenses and accumulates in the pores of the insulation material. The insulation material transports the condensation back to the surface because of its inward directed capillary forces and the ability to conduct water in its pores. The water is discharged from the surface into the room. In the last 20 years, numerous insulation systems have been developed and optimized for interior insulation use. The development objective for diffusion retarding systems is the reduction of the insulation value and the improvement of the durability of foil systems. Multi-functionality is the central development goal for diffusion-open, capillary-active systems. This requires an extensive development effort. The improvement of the insulation value, the humidity regulation, the integration of fire protection functions, the soundproofing, and also the coupling to existing structures is crucial for the structure. This multi-functionality leads to an optimization process, so that different interior insulation systems can be used wisely, depending on the requirements of each interior insulation system.

Abbildung 2. Beispiele für unterschiedliche Dämmstoffe, die als Innendämm

Figure 2 Examples of various insulation materials that are used as interior insulation

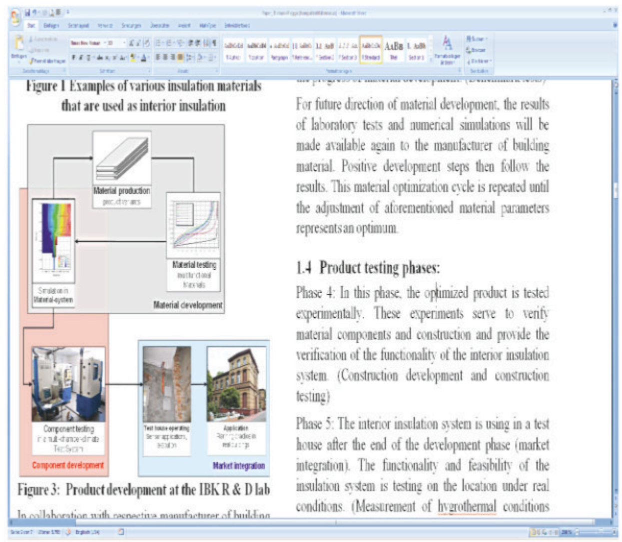
Figure 1 Examples of various insulation materials that are used as interior insulation

Figure 3: Product development at the IBK R & D lab

For future direction of material development, the results of laboratory tests and numerical simulations will be made available again to the manufacturer of building material. Positive development steps then follow the results. This material optimization cycle is repeated until the adjustment of aforementioned material parameters represents an optimum.

1.4 Product testing phases:

Phase 4: In this phase, the optimized product is tested experimentally. These experiments serve to verify material components and construction and provide the verification of the functionality of the interior insulation system. (Construction development and construction testing)

Phase 5: The interior insulation system is using in a test house after the end of the development phase (market integration). The functionality and feasibility of the insulation system is testing on the location under real conditions. (Measurement of hygrothermal conditions

Figure 3 Product development at the IBK lab

In collaboration with a number of manufacturers of building materials, the phases of material development are running through several times until a suitable product is optimized (Figure 3). Subsequently, the construction development and market integration is done through test houses and applications [2].

2.2 New Windows Technology

[3] Even in new buildings, windows are the weak point of the thermal building envelop. They are critical points in terms of comfort (cold draft risk, radiation losses), hygiene (moisture, mould) and air tightness. To avoid this, a window in central European climate has to achieve an U_W-Value of 0.80 W/(m²K). The minimum temperature factor f_{Rsi} between the window element and the building structure has to be higher or equal 0.7 (according to German Standard 4108, part 2) and the window to be airtight. Furthermore ventilation systems have to be implemented to the building. Using recent Passive Houses components, these targets can be met, but often collide with conservation issues: firstly huge and

insulated window-frames does not fit to filigree historical structures, secondly triple glazing leads to heavy glass panes and require massive window-frames, thirdly the light reflecting properties of IGUs cannot bear the historical glass panes and finally historical windows are usually subdivided into many sections. Trying to adopt this zoning to current state of the art windows, will lead to large frame-fraction, higher spacer length and cause additional thermal losses and reduced solar gains.

The recommended solution is to separate the thermal insulation layer from the window as it is seen from outside the building. Thus the (triple glazed) insulation layer can cover the needs of comfort, hygiene and air tightness, while the outside layer can perfectly fit to conservation issues and even can consist of a refurbished historical window. Depending on the special situation of the protected building, the layers can be more or less separated to each other: In a coupled window, they are directly connected to each other. This is the cheaper solution. In a box window, you are totally free in the design of the outside visible layer and the higher depth of the combined frames can make the installation in the wall more easily compared to a casement window. In addition, the 4th glazing improves the thermal properties and raises the temperature of the glass edge.

Using the recommended system in new buildings is of cause possible and, because of the thermal enhancements by the 4th glazing reasonable especially in cold climates (the Alps, North- and East Europe)

- Smartwin historic – coupled window

Inside glazing without sections covers the comfort and hygiene needs and the air tightness. Outside glazing corresponds to the historical issues of the building like mullions and transoms and light reflecting properties of the glazing. This type is best to be installed in the thermal insulation layer of the wall. Use in combination with a ventilation system (Figure 4).

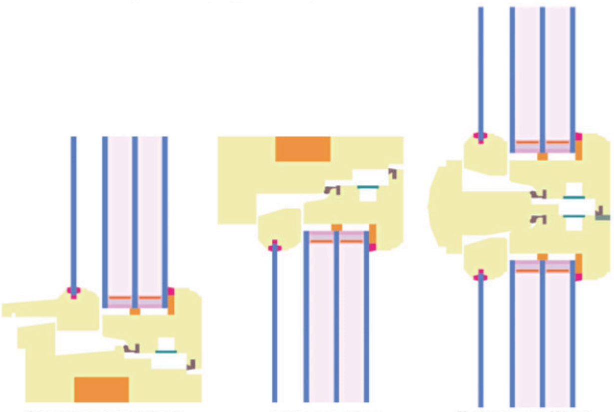

Figure 4 smartwin historic – coupled window

- Smartwin historic – box window

Inside glazing without sections covers the comfort and hygiene needs and the air tightness. Outside glazing corresponds to the historical issues of the building like mullions and transoms and light reflecting properties of the glazing. Even refurbished historical windows can be used as outside layer. Possibly be easier to install on the wall (Fig. 5).

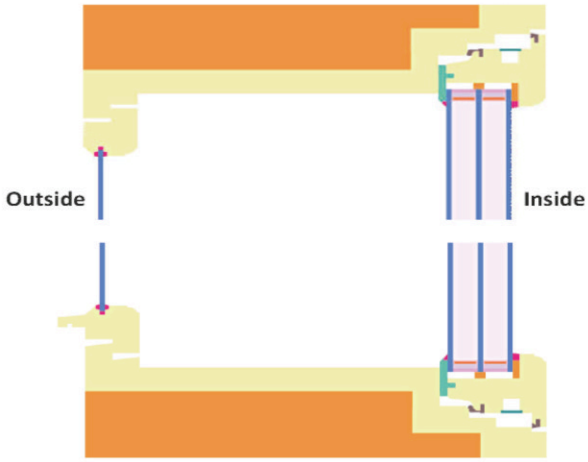

Figure 5 smartwin historic – box window

For most listed buildings, recent high energy efficient windows do not fit because of their huge frames and distorting mirror effect, caused by IGUs. The recommended solution gives the possibility to combine keep the historical habitus of the window as well as to achieve comfort and hygienically needs of a modern window. Feedback of was given by Conservator of the city of Bolzano: Generally positive impressions of the frame and its dimensions, distributions and proportions are acceptable, and regarding the mirror effects, the single outside glazing has to be improved in the future.

2.3 Innovative wireless sensor network system

[4] Monitoring methods based on wireless sensor devices are novel investigation techniques in rapid progressive development both from the software and hardware standpoints, in addition to data handling and processing.

A preliminary market search for wireless building automation solutions has shown that pioneering systems have been proposed by leading firms and that WSN can be a reliable technology. However all the proposed systems are thought for new buildings rather than for existing or historic ones, i.e. they do not provide ability to create interoperability between new applications and existing sub-systems or they do not take typical problematics of historic structures into account.

A new flexible WSN for real-time monitoring of historic buildings was designed inside the Micrel group of the Electronic Engineering Department (DEIS) of Bologna University with the aim to optimise its performance with particular attention to the autonomy and reliability of the whole network. Specific objectives were formulated: physical node size not exceeding a few cubic centimetres; sensors lifetime from several years to tens of years with 2 commercial AA batteries; field configurability of the node with multi-hop radio link, modularity of the WSN together with dynamic deployable capabilities; easy extensibility; optimised trade off between lifetime and quality of service (QoS) of the network; standard protocols for WSN and thus ability to communicate with already on-site components; consideration for wireless actuators which can considerably reduce installation efforts in historic buildings.

- Node architecture

To develop the WSN, after having analysed several platforms present on the market by selected parameters such as architecture flexibility, power consumption, SW accessibility, hardware programmability, platform connectivity and ability to expand internal sensors, the team in DEIS has chosen the Wispes W24TH node, which is a wireless sensor device compliant with Zigbee PRO protocol.

The node can act as coordinator, router or end-device depending on the downloaded firmware can build up network with thousands of nodes (ZigBee capability). The core of the system is a 32-bit microcontroller. The CPU permits development of complex applications and distributed data processing. The system is provided with a series of on-board sensors (see next sections). Moreover, W24TH is equipped with a microSD card reader for local storing, data logging and backup, a USB-battery charger, a 32 kHz quarz oscillator with real time clock library, a 20-pin expansion connector and a power management subsystem. This provides the facility to switch off via SW the whole system with the exception of the microprocessor enabling 8 µA power consumption in sleep mode for extremely long battery life (battery charge status is provided on the power management system). The 20-pin expansion connector presents numerous features for the most common communication protocols which directly connect any digital device to the internal microprocessor, and allows the W24TH to be connected to several expansion boards such as multi-channels acquisition interfaces, actuators, USB, KNX devices, energy harvesters (solar, wind, thermal gradients, vibrations) and more (10 general purpose Digital Input/Output (CGIO), input analog signals which allows reading any analog sensor, e.g. thermistors, pyranometers, DC power supply to power directly external sensors or expansion boards).

The microSD card reader connected to the microprocessor as well as each sensor can be electrically disconnected by the power management subsystem (Fig 6). Firmware upgrade of the node is permitted by using download over-the-air (OTA) facility. Nonetheless, JTAG for Firmware upgrade, as direct connection to the board, is present as it is appreciated by the firmware programmer to debug new functionalities.

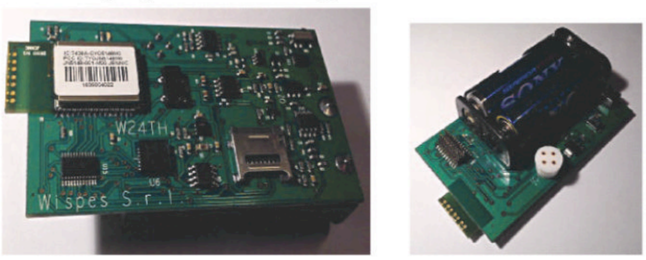

Figure 6 Wispes W24TH microcontroller.

All these features in a single connector allow a variety of possible combinations and solutions in the same wireless network using the same core as building component, without any power or interface constraint. For example it is possible to connect simple sensors or specific designed expansion boards such as: multi-channel acquisition interfaces (e.g. for more than 10 external thermistors, pyranometers, ...); multi-channel actuators (e.g. on-off switches, dim actuators...); converters for the most used home and building automation protocols (e.g. LonWorks, KNX...); converters for the most used industrial and home data buses (RS232, RS422, RS485...); USB and Bluetooth interface to directly manage the WSN using PC, handheld devices or Smart phones.

- On board sensors

The sensors already embedded on the board can cover the large part of applications: temperature, humidity, ambient light sensor, 3-axis ±2g/±6g digital output voltage linear accelerometer and multi brand full controlled semiconductor metal oxide (MOX) gas sensor interface (TO-39 (solid TO-5) socket, heater software voltage regulator (3% resolution), heater current reader, sensor resistance reader, multi brand sensors facility, gas measured [4].

3. Possibilities of hygrothermal evaluation of wall constructions

The moisture protection must be considered a priority in the renovation planning to ensure the permanent success of an energetic building renovation. The following should be considered as well: the formation of condensation, rain, ascending humidity and introduced building moisture and thermal bridges of some construction. Another important aspect concerns the compatibility of interior insulation and underground. For an interior insulation system to become functional, multiple layers have to be considered. The interior insulation should be dimensioned so that the surface condensation is avoided and the internal condensation is limited, so that the obtained drying potential remains. Calculation methods (e.g. COND) and simulation programs (e.g. DELPHIN) are currently available as planning tools for the planner. The use of these planning tools requires knowledge of each required building material parameters. Manufacturers are usually ready to allow the determination of not yet existing parameters for their new materials. For old building materials, appropriate databases e.g. MASEA are available [2] [5].

4. Application of new building technologies based on practical examples

Sustainable functioning of the construction has the highest priority of the energy-efficient renovations of the listed buildings. The protection against moisture is the first priority, followed by heat protection. Some constructions are very sensitive; therefore, scientific monitoring and other innovative technology of energy-efficient renovation would be appropriate.

4.1 Example of building: Hampel Warehouse City in Potsdam

The four-story granary building was built in 1834/35 as a timber frame construction and faced later with red bricks, according to the design of Karl Hampel and collaboration Karl Friedrich Schinkel. After 10 years, the building was enlarged at the corner areas. Each of the last three window axes increased like a tower with an extra floor. The remarkable design quality of this early industrial building defines the extreme historic value of this construction. The general description of the building structure shows that the granary is a timber-framed construction. The building was subsequently veneered with red bricks to reduce driving rain entry into the construction. Due to high driving rain, the façade has been provided by Schinkel with a transparent water-repellent paint. The enlargement at the corners has been carried out with a grouting grout [7].

Figure 7 Warehouse city in Potsdam.

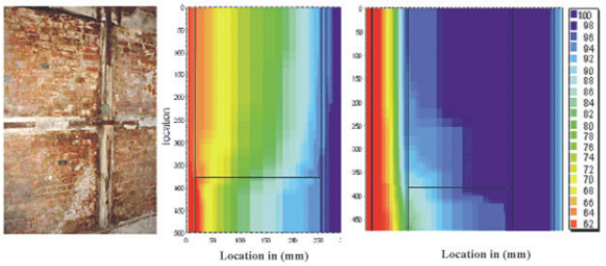

Figure 8 timber-framed construction (inner wall-left), range of simulated relative humidity uninsulated center, and right with 80 mm clay cork insulation.

During the planning of the interior insulation the specific situation of the granary is taken into account. Hence, an open-diffusion clay insulation and cork- diatomaceous systems that is specially adapted to timber-framed constructions is used. A 12mm thick moisture regulating plaster over reed rabitz is applied inside. The energetic evaluation of the whole construction assigns the chosen buildup the EnEV-Standard 2007 minus 28% [2].

Figure 9 interior insulation System (insulation loam cork) Warehouse city in Potsdam.

Figure 8 demonstrate clearly the hygric situation for both the existing and the insulated status. Insulated wall structures are relatively dry close to the inner wall surface, but the humidity increases towards the outside. Because of the insulation, less heat gets into the construction, whereby evaporation will be limited. If the penetrated moisture cannot dry due to driving-rain load during the cold period of the year, the risk of frost damage for the historic brick increases. Therefore, the rain entry is reduced through a surface treatment according to Schinkel. A classical driving-rain protection is not realizable using historic coatings. For this reason, a hydrophobic impregnation with Silane- Siloxancreme for the wall areas and a brick grouting grout for the tower areas is adapted. Damaged joints have to be removed and then grouted with a suitable, color coordinated joint material. According to Heinze et. al. (2010), the adaptation of the hydrophobic impregnation occurs through adjusting the concentration of the hydrophobic agent on each brick. The optimization goal is therefore the diffusion openness with optimal drying capacity and sufficient protection against driving-rain too.

4.2 The case study of Palazzina della Viola

[4] The Palazzina della Viola is one of the 2 case studies, placed in Bologna, Italy, out of 8 cases in the research project 3ENCULT. It is a load-bearing masonry building started at the very end of the 15th century (1497) and it has probably undergone numerous modifications throughout the centuries. Palazzina Della Viola was defined as a "jewel of the Renaissance art". It has also a high cultural value, as it presents a painted timber ceiling and the masonry wall is frescoed. In addition, the light amount along with the temperature values tent to be always excessive, with high preservation risks for the decorations, and uncomfortable conditions - including glaring - to users (the room is a smaller meeting room). The above schematic information is useful to understand why more attention during testing and monitoring, summarized in the following, was devoted to these two rooms.

Figure 10 Palazzina della Viola.

In Palazzina della Viola, an extensive experimental work was carried out by DICAM Dept. including several survey campaigns aimed at investigating the health-state of the building from both structural and energetic viewpoints. Repeated measurements via several non-destructive techniques were performed in different time periods, according to the development of the refurbishment works (i.e. before, during and after the interventions). At the same time, the wireless sensor network, which was installed just before the beginning of the restoration works and later improved, was continuously monitoring. Since about 6 months, a network of about 40 nodes is up and running in Palazzina, with the sensing nodes distributed on the 4 levels, from basement to attic. Out of the 15 nodes located at the first floor, 6 are in the large hall and front loggia. These 6, in addition to occupy static positions, may be used as mobile monitoring stations for specific measurement campaigns or surveys of dynamic phenomena. In fact, in historic structures usually it is necessary to carry out many analyses and tests for diagnostic purpose, so that the high inefficiency and decay be properly faced and solved or reduced. While a number of non-destructive testing (NDT) techniques exists for investigation of the structural and material consistency and degradation, few are the techniques available for experimental investigations of energetic issues and no or very limited experience is at hand on their application to historic buildings which are characterized by very different age, dimensions, volumes, materials, construction techniques and problematics. Thus knowledge in energetic field relies greatly on numerical simulations and estimations from power and fuel consumption. Research is working on extending the testing aims of available NDT techniques to energetic problems, thus also integrating better the energetic and structural diagnostic in a common viewpoint. A new approach would be to extend the aims of monitoring to include testing of particular situations or conditions. This may imply modifying the role of the monitoring system from passive reader to active tester. In this view, the position, data frequency acquisition rate and orientation of one or more nodes may need to be dynamically varied according to the testing aims. The verification by WSN of aspects such as the following seems to be of feasible and particular interest in view of an integration of energy and structural issues.

- Monitoring light distribution

In the case study, the high amount of light entering from the large glazed surface of the building envelope needed to be somehow controlled and reduced. A post processed luminance map of the front loggia from data in as-is condition is presented as an example (Fig 11) showing that the measured values in a cloudy end January day are already considerable (1130 to 2620 lux) and may lead in other seasons to glaring in people entering the room and to degradation risk to the frescoes on the wall. Interesting in the present discussion is that a measure of illuminance done by hand-held lux meter at the position of the WSN nodes at the same time instant of data acquisition by the network has shown that the resolution of the inexpensive micro-sensor plugged on the nodes is satisfactorily comparable with a specialized tool like the lux meter (Figure 12).

Figure 11 Visible image of the front loggia at the time of luminance survey (left), corresponding luminance distribution (right)

These results underline that the nodes of WSN with light sensor may be used in place of a lux meter or in addition to it monitoring continuously the daily or seasonal variations of ambient light without the need for specialized equipment or personnel, in an easy and inexpensive way [4].

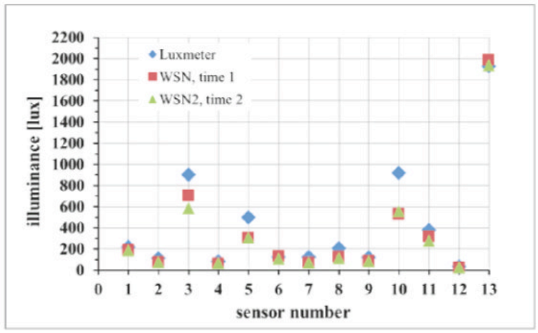

Figure 12 Illuminance values by lux meter and light sensor in WSN node.

- Air flow dynamics

Dynamic modelling is widely used in energetic field as a prognoses tool of building problematics, for example energy losses through thermal bridges (windows, beam-ends, ceiling, building envelope) and for modelling air dynamics inside the building between rooms of different volume, height, sun exposure. As an example, the air temperature values obtained in May 2012 at the same point of the front loggia but at 4 different heights for a time period of 36 hours are shown (Figure 13).

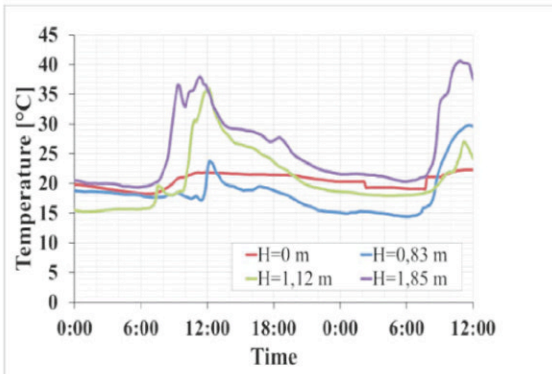

Figure 13 Variation of air temperature values collected in the same point but at different heights in the front loggia (1st floor).

The environmental parameters collected in the large hall at the 1st floor during the experimental campaigns in May 2012 are visualized also as 2D images representing vertical or horizontal sections of the room. These maps were obtained from the values at 28 positions of a grid by moving only 4 wireless sensors across the room, at the same height, and repeating at various heights. The 2D images have been created for air temperature, relative humidity and light in order to evaluate on one hand, their distribution/ variation in the room at different time instants during day and night and on the other, to reach a complete hygrothermal characterization of the room (Fig.14). The comparison of the air temperature maps obtained at different hours of the day show the daily variations of this parameter across horizontal section of the hall (Fig. 14) and give important information about the indoor climate of this room. Positions with temperature differences up to 10°C can be found indicating a bad distribution of the heat in the room, resulting in a scarce comfort. Among other purposes, these data are also used to corroborate results recorded by different or alternative testing techniques. As an example, in figure 14 (right) it is reported a map of values of air temperature collected via a portable thermo-hygrometer, at nodes of grids marked on the floor. In a different experiment by WSN, dynamic monitoring was applied for tracing air movements indoors between the loggia and the hall with the same aims of a novel previous experiment conducted by IR monitoring.

After heating the loggia, and opening one connection door with the hall, the entering flow of warm air was monitored along a vertical plane section in front of the door. 6 mobile nodes located at different heights and distances from the French door, although in the same plane have monitored this dynamic event continuously and with high precision. An example of results present in figure 15. From these data different snapshot of air dynamics can be reconstructed [4].

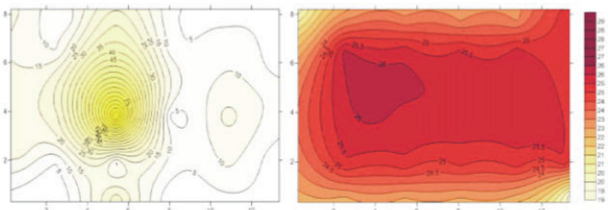

Figure 14 Maps of light (left) and air temperature (right) at 1.75m height measured in May 2012.

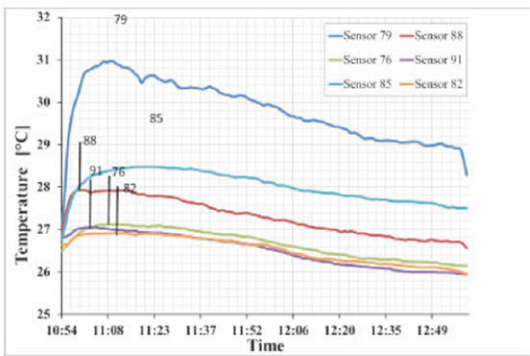

Figure 15 Results of convective air fluxes monitoring (between the front loggia and the main hall).

4.3 School of industrial engineering of Béjar

[8] The Industrial Engineering School (Fig. 16) located in Béjar (Salamanca, Spain). The current building of the Industrial Engineering School was built between 1968 and 1972, following the design project of the architect Manual Blanc Díaz. The formal definition of the building, characteristic of the Modern Movement, supposed a rupture with traditional architecture of the region in that period. It is not a catalogued building as cultural heritage, but its historical and architectural values lie on its formal character and the social and economic impact that its construction had in the region since it is the first building of the University of Salamanca in the city, adding value to an institution previously established (19th century).

Figure 16 External view of the building's main façade.

The state of conservation of the building is considerably good, although it has certain pathologies due to the humidity in cantilevers. The main detected problems, however, are due to low comfort conditions in the indoor spaces (both thermal and lighting) and high energy consumption because of a design little concerned about passive conditioning strategies, as it is usual on all buildings designed before than the energy crisis of 1973.

In a first approach to the diagnosis of the problems of the building, the following aspects were detected: over-heating during the warmer months, deficient heating distribution system, manual control strategy for cooling system elements, oversized lighting system in corridors and halls, inefficient lighting system, underutilization of daylight, and problems due to the low level of isolation and infiltrations.

Considering all aforementioned aspects, a methodology for problems diagnosis and possible interventions' evaluation was established, aimed to quantify them in terms of energy, comfort, economic, etc

- Methodology for diagnosis

The interventions proposed for this type of building are focused on three objectives: conservation of the historical value, energy balance improvement and comfort conditions improvement, acting on the building envelope, the energy systems, and indoor comfort conditions. The validation process of these proposals combines the use of three diagnosis resources: the energy performance simulation, monitoring and measurement processes and non-destructive testing in the building. The main objective of this methodology is to establish a quantifiable basis, based on scientific foundations in order to assess the impact that some energy efficient interventions may have in this type of building.

- Energy performance simulation

Two energy performance simulation tools have been used in order to simulate the thermal behaviour of the building and the annual heating and cooling demand (Fig. 17): PHPP and TRNSYS.

PHPP, developed by the Passive House Institute and used to the certification of passive houses, has been used in the framework of this project in non-residential existing buildings as in this case study. It is a static simulation tool, where the climate data uses average monthly values, which causes some un-certainty. On the other hand, TRNSYS uses a dynamic calculation engine, where the simulation is developed hourly, which results in more precise results.

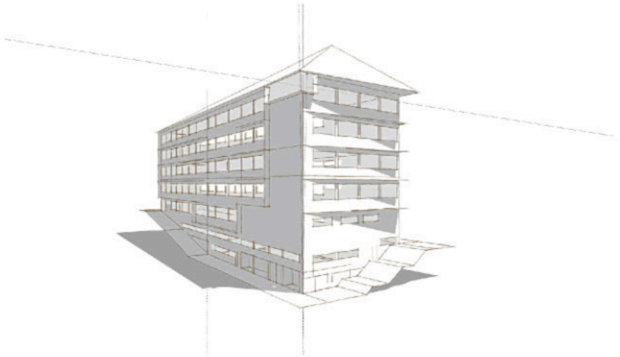

Figure 17 3D model for simulation in TRNSYS.

In this case, the cooling system is minimal, being the cooled area of 150m², which supposes only the 2% of the heated area. Also, in summer periods the occupancy level of the building is very low. Therefore, the simulations are focused on the heating system energy demand.

As it is shown in Table 1, annual heating demand is quite similar, although in disaggregated losses and gains there are substantial differences: transmittance losses (a 30% less in PHPP) and ventilation losses (a 30% less in PHPP), while solar gains are reduced in an 81% and internal heat gains in a 40% in PHPP compared with TRNSYS. In this sense, could be said that PHPP penalizes the calculations both in summer and winter, and this tool could not be useful for certain buildings (e.g. in buildings with low insulation level).

The main difference probably lies on the considerations used by PHPP regarding climate data, where the use of average monthly data is not precise enough.

Thus, while PHPP considers the ventilation air in a constant temperature throughout each month, TRNSYS considers its variation. In the same sense, these considerations affect the transmittance (due to the temperature differences), the systems efficiency, and, especially regarding solar gains, where the dif-ference between annual average values used by PHPP and those used in TRNSYS is very different. It has been verified that using the data provided by TRNSYS in PHPP, the solar heat gains determined by both tools resemble much more.

Heating energy balance	PHPP (kWh/m2a)	TRNSYS (kWh/m2a)
Ventilation	17.90	25.70
Transmittance losses	94.70	154.89
Solar gains	11.60	62.72
Internal heat gains	13.00	22.23
Convection		12.26
Radiation		9.97
Annual heating demand	88.00	95.64

Table 1 results for comparing simulation tools

After the analysis of these results, and understanding that TRNSYS simulation should be more precise in the disaggregation of the heat losses and gains, as it uses hourly data, this will be used as baseline simulation for evaluating proposed interventions.

Table 2 shows the obtained results for base lining (Simulated with TRNSYS), where thermal bridges and air tightness level have been included in the simulations. Comparing real consumption data (≈70 kWh/m²a) and simulated energy demand (Table 1), it is verified that the covered range is not sufficient in order to keep the indoor parameters in comfort conditions during the heating period. By simulating the existing heating systems, the energy consumption is similar to the simulated demand and under this premise, temperature conditions are out of comfort parameters in approximately the 30% of the heating period.

Table 2 TRNSYS-Simulation results for base lining

Heating energy balance	kWh/m²a
Controlled ventilation losses (rate 0.3h-1)	24.70
Transmittance losses (incl. thermal bridges)	141.15
Infiltrations losses (ACH rate 0.14h-1)	25.85
Solar gains	62.72
Internal heat gains (conv.)	12.26
Internal heat gains (rad.)	9.97
Annual heating demand	106.75

- Monitoring and measurement

The monitoring system first and second step has been developed focusing on the generation of a baseline of energy performance indicators and its integration in the control strategies. For the evaluation and the integration of new solutions, two test rooms have been selected for evaluating the comfort conditions and the performance of the energy systems. The selection criteria for these rooms are based in the existing energy systems and the replicability of the strategies in the whole building. Thus, the library is one of these spaces as it is the only room in the building with both heating and cooling systems and with use also during the summer, presenting comfort problems. In these spaces, temperature, humidity and illuminance level sensors have been installed together with occupancy sensors, in order to analyse the occupancy patterns and establish the most adequate control strategies. Apart from these comfort sensors, electrical and thermal energy meters have been installed for analysing the energy performance of the building before and after the implementation of the efficiency strategies.

- Non-destructive testing

In all building energy performance simulation it is necessary to quantify the medium annual rate of air tightness, which normally is very different from the estimated values used in the first steps of the calculations, which are almost always optimistic. The tests results show how the building envelope presents a very low level of air tightness ($q_{50} \approx 10.0$ m³/m²·h), due to three main points of air entrance: the different rigidity of the structural elements made of reinforced concrete and the brick walls without anchoring elements, the construction deficiency and due t the circulating air coming from adjacent locals through the camera above the ceiling. This problem becomes important when heated and non-heated rooms are related.

- Retrofitting strategy

The retrofitting strategies deal new efficient solutions in order to solve the problems detected in the building. The combination of diagnosis tests, simulations and the monitoring system allow detecting the main solutions in order to improve both the energy performance and the comfort level. Also, renewable energy sources could be integrated in order to reduce the final energy consumption from the grid. According to the characteristics of the building, a biomass boiler could be integrated, replacing the existing boiler, while the integration of other sources such as photovoltaic would mean a higher impact in the building and it needs to be evaluated with the other key aspects (historical value, etc.). The following table summarizes the interventions that could be applied.

Table 3 Proposal of interventions

	Energy efficiency	Comfort	RES integration
Passive solutions			
Insulation	x		
Air tightness	x		
Active solutions			
Thermal distribution	x	x	
Efficiency of thermal/ lighting equipment	x		
Solar PV	x		x
Biomass boilers	x		x
Control optimization			
Lighting system	x	x	
HVAC system	x	x	

This methodology covers the evaluation of the proposed interventions in terms of energy savings, CO_2 emissions reduction, comfort conditions improvement, economical investment, life-cycle assessment and conservation of the historical value.

The benchmarking system for evaluating the reduction of the energy demand has been established considering the percentage of the demand reduction compared to the baseline demand. Thus, the different strategies can be compared. This benchmarking system is combined with the evaluation of the other key aspects considered in the methodology. The evaluation of the comfort improvement will be fulfilled after the second reporting period where the values of temperature and illuminance will be analysed in comparison with the baseline. Thus, the benchmarking method for these improvements will be based in the period of time in which the temperature and illuminance levels are in comfort range [8].

5. Summary and Conclusion

Energy-efficient renovation does not have to conflict with the respectful handling of our architectural cultural heritage. The use of new technologies in historical monuments should be accompanied by an advanced evaluation of renovation methods (e.g. by building physics laboratory tests and application of modern simulation tools). The historic preservation as well as the hygric-energy performance of buildings should be considered as well. Interior insulation system, a new windows technology and innovative wireless sensor network are presented as a specific solutions used in this project. Interior insulation of historic buildings represents a challenge in several aspects. Are new materials compatible with the existing building and does it make any sense to postulate insulation at all? What is the potential for energy budgeting? But risks of damage also have to be quantified. How are the utilization requirements in accordance with protecting of the building envelope? The energetic renovation and conversion offer a chance to preserve valuable and culturally relevant buildings. For this reason, it is required that the planning of interior insulation agree with the construction. The examples show that the following topics are significant for this planning: selection and dimensioning of an internal insulation, moisture load of the structure and driving-rain protection, realization of construction details and thermal bridges. The use of special technologies such as measurements and laboratory tests for building diagnostic and material valuations as well as the numerical simulation method for coupled moisture and heat transfer processes are essential to implement this planning. Complex geometric details such as window connections or ceilings integration can also be evaluated and optimized. Condensation ranges and thermal bridges will be shown and thus construction damages are sustainably avoided. In this article, the function principle of a capillary-active interior insulation is explained. The use of an interior insulation system in Potsdam building is shown that capillary-active interior insulation has a great impact on energy-saving renovation of historical buildings.

An advanced monitoring system was installed in a case study in Bologna. The experimental surveys carried out have shown the convenience and easiness of use of WSN implementing a number of micro-sensors. Values of different environmental parameters may be collected at the same time instant without the need for using different and more expensive testing equipment. An innovative monitoring approach was suggested consisting in using the wireless sensor nodes as mobile nodes. Example of profiles and 2D maps of light distribution, vibrations and air flow dynamics were presented. Thus, WSN may be a reliable and robust technology and may provide the ability to create interoperability between new applications and pre-existing subsystems.

Some preliminary conclusions can be learned from the use of the proposed methodology in Béjar case study. Regarding the simulation tools, its use is essential in order to evaluate the aspects that can be improved. Low or medium impact strategies can be deployed (i.e. acting on the building envelope), which allow conserving the historical value, and achieving a reasonable energy efficiency improvement. The use of TRNSYS gives a more precise description of the disaggregated energy demands, and the model validated with real data. On the other hand, certain simplistic strategies, as the redistribution of the circuits based on the occupancy patterns or the optimized control of the lighting and thermal systems allow achieving energy savings and improving the comfort levels. These interventions have a low impact in the historical and cultural value and the global energy consumption can be reduced in the whole building through an extrapolation of the results of the tested rooms by developing a study in detail for the rest of the spaces.

In this context, the energy efficient upgrade of historic building construction is safe under condition of detailed knowledge in above-mentioned fields. This lead to energy saving and CO2 reduction, protection against condensation and mould growth and prevention of damage after window exchange, improvement of thermal comfort and increasing value of renovation buildings, keeping old brick masonry constructions as they are, and also lead to fast heating for temporary used rooms.

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