3encult
EFFICIENT ENERGY FOR EU CULTURAL HERITAGE

D 3.1 Discussion Basis for Multidisciplinary Workshop

Report on Energy Efficiency Solutions for Historic Buildings

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Author(s)	Pfluger Rainer, Paolo Baldracchi
Co-author(s)	Matteo Orlandi, Wilfred Pohl, Zeno Bastian, Daniel García, Alice Quinterio
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0 Abstract

The report present the available solutions for energy retrofit of historic buildings. The objective is to find out the open questions stimulating the discussion among the 3EN-CULT project partners sharing literature references, expertise and approaches.

The above considering that the diverse involved stakeholders have diverse vision of the solution: product oriented (producers aim to sell the best product) or approach oriented (consultants aim to advise the best solution) or RTD oriented (researchers aim to solve general problem and use case studies for assessment) or cultural heritage oriented (curators aim to preserve artistic and historic value of the building). Stated that for historic buildings the aims could contrast each other there are several open questions and step forwards to be done.

After collecting relevant technical-scientific literature and some partner publications/report on the matter of energy retrofit a brief summary for each topic foreseen in Annex 1 was realized and some report ed questions seem useful to lead the work towards energy saving and cost-effective (for the wide spreading outside the FP7 project framework) solutions.

The literature and expertise review gave some ideas on potential development on the basis of the demands from both energy and cultural heritage point of view.

1 Introduction: The path to energy efficiency - individual solutions for historic buildings

There are many techniques available today, which are originally developed for new buildings in order to enhance comfort and energy efficiency for dwellings and non-residential buildings. A lot of lessons learnt from low energy and passive houses in terms of new buildings can be transferred to the wide field of refurbishing and retrofit. The basic principles of building physics are valid for both, but individual solutions have to be found, to adapt the technical procedures as well as the available products.

If it comes to historic buildings, additional questions, such as preservation and aesthetic aspects arise. Again, individual solutions have to be found with advantages and disadvantages which cannot be weighted clear without ambiguity. Moreover, it is a widely interdisciplinary field. The consortium of the 3ENCULT-project gives the chance to bring together all this knowledge of experts necessary to find optimized solutions and to disseminate them on an international basis.

The solutions review in the following is based on literature an direct experiences of the partners. Starting from that point a path to bring energy efficiency in historic building taking into account both the technical and cultural heritage aspects has been discussed and decisions taken towards the development of solutions beyond the state of the art, They will be theoretical analysed and assessed under actual working condition when applied in the case studies.

2 Core issues for discussion

In order to have a good overview about the knowledge on key issues within the project, several information reviews where written (listed in chapter 3). They are referred to within the following chapters. Additional references are given to each subtask.

2.1 Subtask 3.2.1: Interior insulation **[responsible: TUD, REMMERS, ARUP]**

2.1.1 State of the art

The information review papers [1] and [7] give an overview about the advantages and disadvantages of interior versus exterior insulation in terms of building physics as well as the preconditions to be fulfilled if internal insulation is applied.

The discussion at the workshop[1] should be focussed on the type, material and application procedure of internal insulation and its characteristics. Jens Engel sent a list with 21 systems of internal insulation with their material, thermal conductivity, vapour diffusion coefficient, coefficient of capillary water capacity, specific density as well as mechanical, geometrical and application characteristics (included in information review paper [1]). This list will be accomplished by further products and system. Each product will be characterized by its pros and cons within an interdisciplinary discussion. Besides these parameters, a lot of other properties have to be taken into account, if it comes to historic buildings. The choice of the appropriate material and system depends (amongst others) on:

- Monument protection requirements
- Building site (local climate) and orientation
- Type, material and thickness of the wall
- Quality of protection against driving rain
- Inner surface quality of the wall
- Construction of the ceilings/separation walls

The choice of thickness of the interior insulation results from

- Monument protection requirements
- Material (hygro-thermal behaviour)
- Loss of living space tolerable
- Comfort criteria and energy efficiency
- Construction of the ceilings/separation walls

Despite several attempts of the German working group of monument protection service, („Wissenschaftlich technische Arbeitsgemeinschaft für Denkmalpflege und Bauwerkserhaltung“ WTA-Merkblatt 8-1-03/D), there is no general rule for the optimum thickness of the insulation, it has to be investigated individually for each historic building for example by DELPHIN or WUFI dynamic cyclic simulation for a simulation time period of several years.

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[1] Join (WP2: demands and WP3: answers) multidisciplinary workshop to be held in Bologna in March 2011 for definition of priorities for developing of energy efficiency solutions resulting of information flow between the two WPs

2.1.2 Steps forwards and open questions

- **Are important products missing in the list?**
- **Which of the products are suitable from monument protection point of view?**
- **Which of the products are capillary active, and if so, how strong?**
- **What about practical experiences with the different products?**
- **What are the pros and cons of the products?**
- **What kind of techniques are used for mounting and sealing?**
- **How are junctions to the internal wall solved?**
- **Are DELPHIN/WUFI data available/missing?**

Finally the products should be grouped and rated for the different purposes within the project. The results will be documented

2.1.3 References

Feist W (Hrsg), *Faktor 4 auch bei sensiblen Altbauten, Passivhauskomponenten und Innendämmung*. Protokollband Nr. 32, Arbeitskreis kostengünstige Passivhäuser Phase III; Darmstadt; 2005.

Feist W (Hrsg), *Einsatz von Passivhaustechnologien bei der Altbau-Modernisierung*. Protokollband Nr. 24. (Darmstadt PHI, ed.). Arbeitskreis kostengünstige Passivhäuser Phase III; Darmstadt 2003:218.

Zeno Bastian, *Altbaumodernisierung mit Passivhaus-Komponenten*. Darmstadt: Passivhaus Institut Dr. Wolfgang Feist Rheinstr. 44/46 D-64283 Darmstadt www.passiv.de im Auftrag des Hessischen Ministeriums für Umwelt, Energie, Landwirtschaft und Verbraucherschutz; 2009:329.

Stirling C, *Thermal insulation: avoiding risk*, BRE; 2002

2.2 Subtask 3.2.2: Airtightness **[responsible: PHI]**

2.2.1 State of the art

The information review paper [2] explains the basic principles and reasons for the need of airtightness of buildings. During the 3ENCULT kick-off meeting, there was a lot of discussion about the necessity of airtightness in historic buildings most of the questions are already answered. The workshop should focus on the practical aspects of airtightness measurement and its implementation in different types of buildings.

As written in [2] even in case of buildings with many leaks and particularly large buildings, the airtightness can and should be measured by pressure test. In this case, the measurement can be performed at 25 Pa instead of 50 Pa. If the air flow rate of the fan is still too low, the test can be carried out using several blower doors. If possible, the building volume can be divided into several parts and measured individually. Practical experiences and solutions should be exchanged in the workshop. They will be documented systematically for the report.

2.2.2 Steps forwards and open questions

- **What kinds of materials are suitable in combination with typical wall/insulation combinations in terms of historic buildings and building materials?**

- **What kind of special problems do occur in historic buildings in terms of airtightness and how could they be solved?**
- **How to detect and quantify individual leakages (tolerable/intolerable)?**
- **Are additional measurements to be done?**

2.2.3 References

Peper, S., Feist, W., Sariri, V., *Luftdichte Projektierung von Passivhäusern, (Airtight Planning of Passive Houses)* CEPHEUS Project Information No. 7, Passive House Institute, Darmstadt 1999.

Peper, S., *Luftdichtheit bei Passivhäusern - Erfahrungen aus über 200 realisierten Objekten (Airtightness in Passive Houses – Experiences gained from over 200 realised buildings)*; Conference Proceedings of the 4th Passive House Conference, Passivhaus Dienstleistung GmbH, Kassel and Darmstadt, 2000.

2.3 Subtask 3.2.3: Moisture transport problems at beam ends

[responsible: UIBK, ARUP]

2.3.1 State of the art

In case of inside wall insulation most experts suggest capillary active thermal insulation materials or a vapour retarder dependent on the relative humidity in combination with airtight construction of embedded wooden beam ends. Nevertheless, moisture infiltration due to air gaps may not be entirely eliminated in such constructions.

2.3.2 Steps forwards and open questions

The assessment of the risk of moisture damage in beam ends in case of air leakage will be performed by means of multidimensional hygrothermal modelling. The influence of the leakage rate on the hygrothermal behaviour can thus be investigated under realistic boundary conditions. The following steps will be performed:

- **Models development?**
- **Cross-validation with existing HAM-tools (Delphin, WUFi)?**
- **Sensitivity Analysis (material properties, leakage rate, boundary conditions)?**
- **Elaboration of design recommendations?**
-

2.3.3 References

Gnoth S., *Köpfe im innengedämmten Außenmauerwerk Heizungstechnisch gestützte Innendämmung bei Holzbalkendecken*. Bauphysik. 2005;27:117-128.

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Sanders, *Modelling and controlling interstitial condensation in buildings*, BRE 2005

Monika Woloszyn, Carsten Rode, *Tools for Performance Simulation of Heat, Air and Moisture Conditions of Whole Buildings*, Build Simul (2008) 1: 5–24, DOI 10.1007/s12273-8106-z

De, Santanu, Nagendra, K., Lakshmisha, K.N., *Simulation of laminar flow in a three-dimensional lid-driven cavity by lattice Boltzmann method*, pp. 790-815(26), International Journal of Numerical Methods for Heat & Fluid Flow, Volume 19, Number 6, 2009

Van Schijndel A. W. M. (Jos), *Heat and Moisture Modeling Benchmarks using COMSOL*, Excerpt from the Proceedings of the COMSOL Conference 2008 Hannover

2.4 Subtask 3.2.4: Windows **[responsible: PHI, ANDRE, ARUP]**

2.4.1 State of the art

Well insulated windows that meet the requirements for Passive Houses have several important advantages: they offer good thermal comfort – even without a radiator next to the window, they have high surface temperatures and thus there is no danger of condensate and mould growth, good airtightness avoids uncomfortable drafts, and of course they safe energy and help cut the heating bill.

Passive House windows are already widely available in a wide range of materials and designs. In [4] the state of the art for windows and energy efficient modernisation is documented.

2.4.2 Steps forwards and open questions

For historic buildings in many cases thin glazing and thin window frames are required. These requirements cannot be met by many of the currently available Passive House windows. The question is, how it is possible to meet the monument protection requirements and still have a very good thermal window quality.

The best approach will probably be to develop a well insulated modular window system which can be adapted to the visual requirements for the individual historic buildings.

Open questions:

- **How to conciliate high thermal performance and lightness for windows in historic buildings?**
- **Could good architecture solutions compensate for lower windows thermal performance?**

2.4.3 References

Kaufmann, Peber, *Optimierte Anschlussdetails bei Innendämmung – Wärmebrückenreduktion und Luftdichtheit*; in [Feist (Hrsg.) 2005], S. 175 ff

(Optimised connection details for interior insulation – Thermal bridge reduction and airtightness, in [Feist (Publisher) 2005], page 175 ff.

C.M. Lampert, *Electrochromic materials and devices for energy efficient windows,* Solar Energy Materials Volume 11, Issues 1-2, October 1984, Pages 1-27

Wolfgang Feist, *Optimierungsstrategien für Fensterbauart und Solarapertur, Arbeitskreis kostengünstige Passivhäuser*, Protokollband Nr. 37, Darmstadt, Passivhaus Institut, November 2008.

2.5 Subtask 3.2.5: Integration of shading systems within window/glazing system [responsible: UIBK, BLL, ARUP]

2.5.1 State of the art

The information review paper [8] provides a list of available integrated shading systems used in current projects. A wide range of products is available on the market: integrated slats, venetian blinds, roller blinds, wire metal meshes, diffusing capillary systems, suspended low-e films and laminated glass interlayer. Some products are suitable to be applied in historic buildings, whilst some of them should be further improved and modified to suit to conservation requirements.

Shading devices could be either fixed or movable. For the last ones, the management of systems' operability should be verified in each application, as it will impact on both internal and external environment.

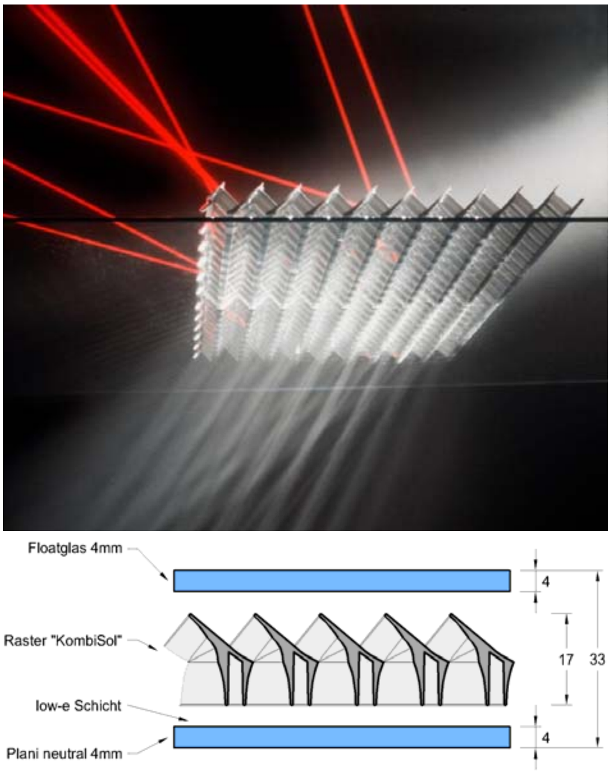
Both solar control and daylighting must be evaluated while designing and selecting shading devices. Workshop's discussion is focusing on the suitability of different shading systems to historic buildings, depending on the use of the building and conservation requirements. The contribution of conservation experts is fundamental to assess pros and cons of each system and possible developments.

The risk while refurbishing the envelope of existing buildings is to focus on the building itself and forget about people and future occupants and users. Therefore, the enhancement of transparent envelope performance has to be pursued considering the sustainability in operation of the designed system, as thermal, visual and even acoustic comfort of the occupants are important performance indicators.

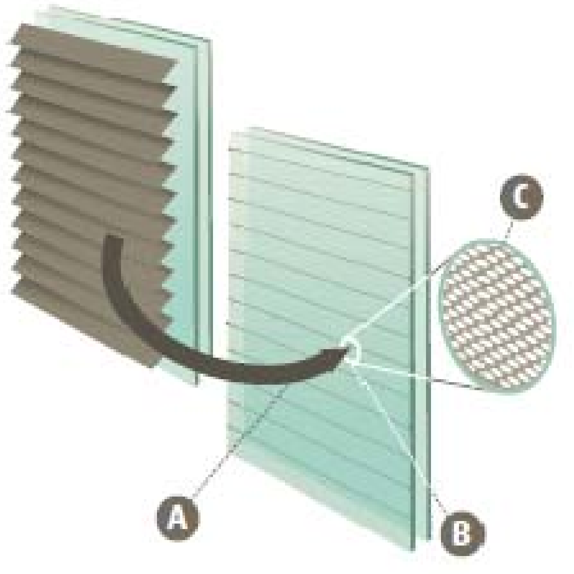
Besides constituting a weak point regarding thermal protection, windows are usually the only source of daylighting in historic buildings. Visible from the outside they also significantly contribute to the appearance of the building. Therefore windows are usually untouchable in historic buildings, especially the frames are usually not changeable. Thus, the possible positions for the integration of shading systems are limited.

In southern regions the single glass type window is very typical for historic buildings, whereas in northern regions casement windows are usual. In case of single pane windows only internal shading systems seem to be suitable. For casement type windows the spaces between the glasses could be used for shading system integrations.

Summarized, two main issues regarding the integration of shading systems within window/glazing systems arise. First, from the conservator point of view the integration of sun shading devices is only allowed in special cases. Second, only a limited number of such systems are available on the market in general.



Example 1: Siteco Micro Sun Shading Louvre.



Example 2: MicroShade^{TM}. Micro-perforated stainless steel

2.5.2 Steps forwards and open questions

The proposed strategy is, to equip windows where possible with integrated shading systems, and to adapt the usage of the rooms and of the buildings where a change of window structures is not possible.

Sun shading has to be considered in connection with daylighting. An optimal solution is a system which incorporates all aspects like daylight provision, glare protection and, sun shading.

The typical window types (casement windows for northern regions, single pane windows for southern regions) have to be improved by individual additions (components), rather than by a replacement by new window products.

Open questions:

- **Possible solutions and limitations for specific technologies?**
- **Compatibility of modern technologies with conservation requirements, depending on projects, case studies and countries?**
- **Adaptation/development of existing technologies?**
- **Dedicated management of Lighting/Solar control devices to meet specific requirements of Conservation (cross to WP4 “Monitoring and Control”)?**
- **Integrated design focusing on both build-up performance and comfort of the occupants?**
- **Smart integration with active system (both mechanical and electrical)?**

2.5.3 References

PhotoSolar A/S. *An der Malling-Schule behalten sie einen kühlen Kopf*. 2009.

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Quaschning, V., Hanitsch, R.: *Shade Calculations in Photovoltaic Systems*; ISES World Solar Conference - Harare, Zimbabwe, 1995 (73 kB).

Quaschning, V., Hanitsch, R.: *Der Einfluss von Abschatungen auf Photovoltaikanlagen in der Landwirtschaft*; 19.Konferenz CIGR Sektion IV, Stuttgart, 25.-28.9.1995.

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Quaschning, V.: *Simulation der Abschattungsverluste bei solarelektrischen Systemen*; Verlag Dr. Köster Berlin, 1. Auflage September 1996.

Quaschning, V.: *Höhere Flächenausbeute durch Optimierung bei aufgeständerten Modulen; 13. Symposium Photovoltaische Solarenergie* · Staffelstein · 11.-13. März 1998 (36 kB).

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Kambezidis, H.D.; Papanikolaou, N.S.: *Solar position and atmospheric refraction*. Solar Energy ol. 44, 1990, pp.143-144.

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Sattler, M.A., Sharples, S., Page, J.K.: *The geometry of the shading of buildings by various tree shapes*; Solar Energy Vol.38 No.3, pp. 187-201, 1987.

IEA, 2006 International Energy Agency. *Light's Labour's Lost*. IEA Publications, France.

2.6 Subtask 3.2.6: Integration of space saving ventilation systems with heat recovery [responsible: UIBK, ATREA]

2.6.1 State of the art

The state of the art about ventilation systems with heat recovery for integration in existing buildings is given in [Feist 2004]. It is an overview about the possibilities of integration of the heat exchanger in the building structure, such as integration in walls and ceiling. Within the last few years, several manufacturers have developed products especially for refurbishing purposes.

However, up to now, in most cases the systems are not really integrated into the structure of the building, most of them not applicable for use in cultural heritage. First attempts are done by the architect Michael Tribus with his development called "LiLu" for refurbishment of class rooms of school buildings (see http://www.michaeltribus.com/events/lilu_volantino.pdf). But also in this system, the ventilation unit applied is a standard heat recovery system.

2.6.2 Steps forwards and open questions

A wall integrated ventilation system with heat recovery was designed by UIBK, which is adapted for the special needs of the protected school building in Innsbruck (Case Study 5). Further development will be done by UIBK and ATREA. The space below the window is used for the heat exchanger, the air distribution for the supply air is located above the window. To avoid any changes at the façade, the ambient air intake is realized below the window sill, the exhaust air outlet is at the window frame.

In general, the following open questions are discussed in terms of integration of ventilation systems in cultural heritage:

- **System to be preferred: centralized or decentralized?**
- **Openings in the ceiling in case of centralized systems?**
- **Duct system: hide or show it?**
- **What is the best location (depending on the type of building) for the integration (wall or ceiling)?**
- **How to realize the openings for air inlet and outlet?**

2.6.3 References

Feist W (Hrsg). *Lüftung bei Bestandssanierung: Lösungsvarianten*. Protokollband Nr. 30. (Feist W (Hrsg), ed.). Darmstadt: Passivhaus Institut; 2004:130.

2.7 Subtask 3.2.7: Analysis of the cost-effectiveness of automatic air flow volume balancing in heat recovery [responsible: PHI, ATREA]

2.7.1 State of the art

Volume flow balancing not only reduces the ventilation heat losses but is also important to avoid structural damage in the building envelope caused by condensate. Not all systems of automatic volume flow balancing are equally useful to achieve an exact and long-lasting volume flow balance. The minimum achievable error tolerance ranges from +/- 5 % to +/- 20 %.

The state of the art is reviewed in [3].The following systems are currently known:

- Measuring rpm and power consumption of the fans
- Baffle crosses
- Hot wire anemometers
- Pressure loss measurement at heat exchanger
- Determination of enthalpy difference at heat exchanger

2.7.2 Steps forwards and open questions

In historic buildings a good airtightness is not always easy to achieve. In this case a ventilation system, that runs with a slight extract air surplus can help prevent structural damage caused by condensate at remaining leakages. However, an unbalance of more than 10 % increases the ventilation heat losses significantly and should thus also be avoided. In order to meet both requirements the automatic air flow balancing must have a low error tolerance. The question, which systems meet these requirements (also for extended periods of operation) and are thus applicable to historic buildings is to be clarified in 3ENCULT. Moreover the economic viability of automatic air flow volume balancing (higher investment costs vs. lower ventilation heat losses i.e. lower heating costs) will be investigated in 3ENCULT.

2.7.3 References

Werner, Johannes und Laidig, Matthias: *Grundlagen der Wohnungslüftung im Passivhaus*. In: Arbeitskreis kostengünstige Passivhäuser, Protokollband Nr. 17, Dimensionierung von Lüftungsanlagen in Passivhäusern, Darmstadt, Passivhaus Institut, Oktober 1999.

Wolfgang Feist, Passivhaus Institut (Herausgeber): *Lüftung bei Bestandssanierung, Arbeitskreis kostengünstige Passivhäuser*, Protokollband Nr. 30, Darmstadt, Passivhaus Institut, Dezember 2004.

2.8 Subtask 3.2.8: Daylighting **[responsible: BLL, ARUP]**

2.8.1 State of the art

In general, the issue of daylighting is intimately connected to the topic of sun shading systems. Concerning historic buildings, where usually neither intensive use of daylighting nor the integration of shading devices were considered, this connection is even stronger and basically reduced to windows. Therefore the state of the art for shading devices described in section **Error! Reference source not found.** (Subtask 3.2.5) is in agreement with the status quo of daylighting systems.

Windows are a main weak spot regarding thermal protection. Thus, they conventionally only account for a very small fraction of the exterior walls of historic buildings. With the condition not to change the appearance of the façade, the need for highly efficient daylight redirection systems arises. Otherwise it is not possible to gain satisfying amounts of daylight inside the rooms.

Example 3: Durlum Light Pipe

Example 4: Durlum Daylight Redirecting Louvre

2.8.2 Steps forwards and open questions

Daylighting has to be considered in connection with sun shading. An optimal solution is a system which incorporates all aspects like daylight provision, glare protection, and sun shading.

Dependent on the respective conditions and the building not only the windows/the façade may be considered for daylighting aspects. There are daylighting systems available on the market that are not mounted at or integrated into the façade. For example light pipes can be installed at the roof and redirect daylight into rooms that are not sufficiently daylight through the windows.

Open questions:

- **Internal surface development and treatments to improve efficiency and effectiveness of natural lighting?**
- **Can historic buildings be daylight-wise evaluated collectively or do daylight and sun shading solutions need to be developed for every single project site?**

2.8.3 References

Bruin-Hordijk and Ellie de Groot: *TD. Lighting in schools*. 1-10. TU Delft

J.C. Lam, D.H.W. Li, *An analysis of daylighting and solar heat for cooling-dominated office buildings*; Solar Energy Volume 65, Issue 4, 1 March 1999, Pages 251-262

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Pohl, W., *Energy efficient daylight solutions, trends and chances*; VELUX Symposium Rotterdam 2009

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Onaygil, Guler, *Determination of the energy saving by daylight responsive lighting control systems with an example from Istanbul*, Building & Environment, 2003

Hausler, *Determination of thermal comfort and amount of daylight*, 2002

Unver, *Effect of the facade alternatives on the daylight illuminance in offices*, Energy and Buildings, 2002

IEA, 2006 International Energy Agency. *Light's Labour's Lost*. IEA Publications, France.

2.9 Subtask 3.2.9: Artificial lighting [responsible: BLL, GELBISON, ARUP]

2.9.1 State of the art

In historic buildings which are listed (i.e. under cultural heritage protection) very often no interventions and additions in the wall and ceiling structures are possible. This is for example the case in the Bologna case study Palazzo D'Accursio, where historic paintings and frescos are present on the walls and ceilings.

This was defined to be a difficult requirement to the artificial lighting installation, which can be fulfilled e.g. by special stand-alone-solutions (floor lamps). At the moment there are not many luminaries available on the market that are aligned for the lighting of historic buildings.

In general it can be said that the artificial lighting in general in historic buildings is very poor. As solutions, consistent with the needs of conservation of spaces, efficiency and energy savings, LED technology can be used and even further developed to provide useful lighting products for historic buildings.

2.9.2 Steps forwards and open questions

For artificial lighting special luminaries (for example floor lamps) have to be developed which meet the different requirements like comfort and health for the occupants as well as architectural, historic and conservational issues.

Such floor lamps should have different requirements, for example

- illuminate the room according to the usage (museum, show case, office, restaurant)
- simultaneously illuminating the paintings and frescos on the walls and ceilings, as well as illuminating special statues and monuments
- take into account conservation issues (spectrum and intensity)
- investment and maintenance costs
- etc.

Open questions:

- **Are other typical lighting solutions for such buildings already available on the market?**

2.9.3 References

Halonen, *Guidebook on Energy efficient electrical Lighting in Buildings* ; IEA Annex45, 2009

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2.10 Subtask 3.2.10: Passive heating & cooling [responsible: EURAC, ARUP]

2.10.1 State of the art

In order to optimize the passive heating and cooling potentialities of an existing building that has to be renovated, an holistic approach has to be implemented during all the renovation process. As an example of such an holistic approach you can see the output of the IEA project "Implementing

Agreement Energy Conservation in Buildings and Community Systems" [Hendriks L., 2003]. Within the renovation process all the stakeholders has to be involved to allow an easier and smoother matching between needs represented by building owner, final users if they are not the owner, conservators and technical/architectural expertise represented by technical/architectural designer and building company.

Within this process the technical/architectural designer has to investigate with the help of the building owner and of the conservators, the "history" of the building to restore. In fact, in order to understand the potential performance of the passive solutions originally conceived during the building design and realization, it is really important to know when the building has been built, which was its original use and its evolution trough out its life in terms of renovations and changes of use. This should allow to better understand its actual architectural concept and structural layout. Therefore a whole geometric survey, the identification of the materials and of the heating/cooling strategy and systems (in case) are needed. Last but not least, data on the location of the building have to be collected: urban context and relative microclimate, height on the sea level, wheatear data, shadow diagram etc.

Once all mentioned above data have been collected a comprehensive analysis of the state of the art of the building can be carried out. This is necessary to lead the choice towards the most suitable solutions in terms of passive heating and cooling for that particular building. Such solutions could recover an original functioning of the building or exploit architectural solutions thought for other scopes or functions.

Passive heating of building is possible through direct heat gain and/or thermal storage methods [Givoni, 1991], that is, using transparent surfaces to gain heat and wall to storage it, making it available for the night. Others solutions are not possible for historic buildings: Trombe wall, Barra system, sunspaces [Givoni, 1991] for conservative reasons. Direct heat gain method is simple and inexpensive, but it depends on climatic loads swings, being the amplitude of the heat wave on the outer surface of the wall based on solar radiation and convection in between the outer surface of the wall and ambient air [Asan, 1998], even if mass could possible attenuate the phenomena.

Especially in not heat or cool dominated climates the passive heating solutions must be studied together with the cooling ones in order to avoid not desired overheating and glaring by daylight. Passive cooling are made mainly by increasing building time constant that allow to reduce building load up to 60%. Designing properly the interior and exterior surfaces of walls allows to optimize interior and exterior convective heat transfer which will lead to a sensible reduction of the cooling loads (from 30% to 50%) [Yang, 2008]. This highlights the closed relationship among thermal mass, natural ventilation and weather conditions for exploiting free cooling potential.

Also the user behaviour can help passive cooling, in particular by window-control. Some algorithms were studied and validated and detailed dynamic simulations can be carried out in order to predict effect of users behaviour on the summer thermal performance for a range of different building constructions [Yun, 2009].

In fact, the influence on winter – and summer comfort is the focal point of discussion about the impact of thermal mass in historic buildings. Due to massive and thick walls, most of historic buildings (besides wooden constructions) do have a high thermal inertia. This effect might be useful for night ventilation in regions with hot summer climate. On the other hand, in case of temporary use of the building during the heating season, high thermal inertia is counterproductive for fast heating of the rooms. Internal insulation decouples the thermal capacity of the wall from the room air, which is good in terms of temporary use, but counterproductive in terms of night ventilation cooling.

Compared to the thermal inertia, the hygric time constants are much longer. In some cases even seasonal storage effects can take place in historic buildings (depending on material and thickness of the walls). Internal insulation might also have effect on the thermo-hygric behaviour of the building.

In some cases, historic buildings are already provided with natural ventilation systems which increase both the comfort in the indoor ambient and the overall energy performance of the building. Therefore, the reuse and reactivation of these natural ventilation techniques should be always investigated [Balocco 2008], [Balocco 2007], [Tablada 2009].

2.10.2 Steps forwards and open questions

- **Which are the best finishing solutions for internal and external side of the building envelope in order to maximize the exploitation of thermal mass for reducing cooling and heating loads?**
- **How many insulation and thermal mass in different climate zones (Mediterranean, Central and North Europe)?**
- **How to combine modern life style needs with original building architectural solutions to keep closed to comfort conditions without distributed air-conditioning systems?**
- **How does static simulation work in hot summer climate? Must the "free gains using factor" to be calibrated?**

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2.11 Subtask 3.2.11: Active energy efficiency solutions [responsible: ARUP, CARTIF, G1S, EURAC]

2.11.1 State of the art

It is frequent that an existing building, in particular an historic one, doesn't achieve current benchmarks in term of energy saving, comfort, security and life safety.

Before starting a refurbishment it is fundamental to carry out an analysis of the actual existing building's performance and condition to understand which areas need to be improved.

At first it is important to study the behaviour of the building without considering mechanical and electrical systems and try to implement the passive strategies to reduce the energy demand of the building.. For instance, with regard to the envelope, in an existing building it is necessary , as often as not, to improve insulation and airtight but it is possible to use the thermal mass of the structures to reduce the peak loads and improve comfort; the use of natural ventilation or day lighting has also to be investigated before starting to design lighting or ventilation systems.

Sometimes the building services of a historic structure can have themselves a historic interest; in this case this options are possible for these systems: remain in use unaltered; be refurbished and re-used; be left for visual effect or for historic reasons but be functionally replaced.

Strategies and effects for using building services, both new and refurbished, in an existing building are described in the review paper [5]. To choose the strategy and the most suitable solution, is common to evaluate which are the most important parameters (KPI- key performance indicators) that has to be considered to design mechanical and electrical systems. Not all of these parameters, connected for instance with comfort and costs, have the same importance; the hierarchy is related to the building function (for instance reduce the noise level could be more important in a hotel than in a shopping mall) and, for a refurbishment, some parameters, strictly related to the building conservation, will be taken into account more than other connected, for instance, with comfort and energy saving.

A typical example is the control of temperature and humidity in an old building where an accurate control of these parameters could be not so fundamental for occupants comfort but it can be necessary to avoid damages of ancient structures or internal furniture.

The most common “actives strategies” are:

- use of high efficiency systems such as condensing boiler, heat pumps, geothermal and heat recovery system, equipments like radiant panels or chilled beams that work with low water temperature and that are able to guarantee high comfort level;
- use of renewable energies (wind, sun);
- advanced automatic control systems; development of suitable control strategies and the retrofitting of the systems conditions

The last one, is a solutions not so explored and used in buildings, and particularly in historic ones. This trend is now changing and ICT-based systems are being taking into account more frequently as can be observed in different programs and projects in progress around Europe [ICT Vision 2009]. In addition, the integration of ICT as an important part of the energy efficiency strategy could address to energy behaviour improvement and operation optimisation of the building, as well as a much more monitored working of the systems. [Schneider Electric]

Regarding the historic buildings, either the absence of control strategies in some cases or the lack of its optimization in many others is the main cause of huge waste of energy and users discomfort. By introducing ICT-based solutions and the Building Management System (BMS) concept, a new scenario for improving building energy operation will be available, in which different services representing advanced control algorithms will take an important role in the overall energy management strategy.

The potential energy savings to be achieved through ICT-based solutions should not be dismissed given that they will bring together the concepts of: intensive monitoring to assess the performance of the building and to show the results to the users, integration of renewable energy sources, independent systems control through specific strategies, users behaviour assessment and involvement in the control strategies and many different services all of them interconnected. [Schneider Electric] [Zamora-Izquierdo 2010]

Additionally, cultural heritage considerations must be taken into account by developing specific services aimed to understand the more restrictive needs of this type of buildings, to adapt the control strategies to the systems installed, to protect special elements which are part of them and to take into account the different climates represented in this particular project.

A review about the state of the art is given in [5].

2.11.2 Steps forwards and open questions

- **Before starting with a refurbishment, which are the main verification that should be carried out on existing systems? Which are the most important devices and equipments that should be checked (generators, pumps, fans, piping insulation, etc.)?**
- **In which cases is it possible not to totally replace the existing systems but make them more efficient?**
- **Which modern high efficiency systems and technologies can be easily used in an existing building without causing damages?**
- **To achieve comfort, to save energy and to preserve an existing building how is it possible to integrate passive and actives strategies (for instance natural ventilation with mechanical ventilation)?**
- **Create a list of typical systems that can be used in a refurbishment considering that, in particular in the old building, suspended ceiling or void floor are not present and it's not possible to create them?**

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2.12 Subtask 3.2.12: RES integration [responsible: CARTIF, ARUP, G1S, EURAC]

2.12.1 State of the art

Solar Systems Integration

The integration of renewable energy systems in buildings, especially in the case of solar, is dealt by a lot of important authors exclusively from a point of view purely technical and functional. It is essential that the solar gain is performed in optimal conditions, but it is also important the system was part of the building as an integrated system. In spite of this, solar thermal is not yet playing the important role it deserves in the reduction of buildings fossil energy consumption, although mature technologies at competitive prices are largely available.

Within existing buildings, it's possible to distinguish between two main groups: rehabilitate buildings with no architectural interest and heritage buildings. Intervention in heritage buildings of high architectural value is clearly more restrictive than in the other buildings. The most common tasks in that type of buildings are maintenance and restoration works, in which the original buildings haven't formal variations. In addition, it's not possible to carry out tasks where the collectors change the orientation or inclination, with respect to the plans of the building, and actions on façade are virtually impossible, being reduced to the integration of solar roofs. An overview of current Building Integrated Photovoltaic systems and an example of façade refurbishment is included in the review paper [6]. Besides, the paper contains an overview of thermally-driven cooling technologies, as solar cooling or similar.

In fact, among the technologies that take advantage of the solar energy, it's important to consider the solar cooling systems. The chronological coincidence, between cooling demand and energy supply in the form of solar irradiance is a good argument for solar-driven air conditioning. The knowledge of the performance data related to solar cooling is important to establish control strategies that lead to an optimal operation of these systems.

The growing desire for comfort has led in recent years to a considerable worldwide increase in the number of buildings with air conditioning. As the energy consumption of air conditioning systems is relatively high, future oriented solutions for a sustainable energy supply renewable energy systems.

To date, the traditional design of solar thermal collector systems for providing hot water in moderate climate zones has generally been based on the idea that excess heat in summer should be avoided, or, at least, kept to a minimum. The use of the summer excess heat for solar thermal cooling therefore offers the opportunity to improve the efficiency of solar thermal systems for the provision of hot water or heating support. However, until today this type of system has not been able to penetrate the market and the accumulated experience and performance data related to solar cooling systems are scarce.

Although there are old references about solar cooling works, this is a technology which is advancing currently and it has evolved in recent years. Among these developments we can find the latest technological developments in thermal chillers, advances in materials and manufacturing techniques, improvement in variable flow pumps.... The use of variable flow pumps improves the control of the installation, which is very important to obtain better performances and results. [Bujedo L. 2008]

It's also important, for the control of the installations, to measure variables (temperatures, flows and pressures), and take data from meteorological station. This is fundamental in order to obtain enough information about the installation and its elements, but it is also necessary to have tools to analyse all this data to achieve better control system. [Bujedo L. 2008 Software]

A review about the state of the art is given in [6].

2.12.2 Steps forwards and open questions

- **In which cases is it possible to integrate the existing systems with renewable energy systems?**
- **Are there solar systems more suitable for existing building?(i.e. could be the thin-film technology in general more suitable than crystalline silicon modules?)**
- **Identify typical space requirements for the most common removable energy systems.**
- **Elaborate a list of solutions that can be used in existing building according to the climate (different solutions for different climatic contexts)**

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3 Information reviews

In the following the lists of partner publications available as published document or as an annex of this report when not thought for publication.

Passivhaus Institut: (published in http://passipedia.passiv.de/passipedia_en/start)

[1] Kaufmann B, Hasper W.: Interior Insulation – basic knowledge

[2] Peper S.: Airtightness in old buildings

[3] Bräunlich K.: Automatic volume flow balancing in ventilation units

[4] Krick, B.: Basic principles for windows, research on Energy-efficient Modernisation

The documents [1], [2], [3] and [4] are also published together as one document in printed version (available at www.passiv.de):

Bräunlich, Kristin; Kaufmann, Berthold; Krick, Benjamin; Peper, Søren: *Passive House Components for Historical Buildings – Interior Insulation, Airtightness, Windows and Automatic Ventilation Balancing*; Passive House Institute, Technical Information PHI-2011/1, Published by Dr. Wolfgang Feist, Passive House Institute, Darmstadt, Germany, 2011.

ARUP:

[5] Annex 1 ARUP, *Passive Active Energy Efficiency*, 2011

[6] Annex 2 ARUP, *RES Integration*, 2011

[7] Annex 3 ARUP, *Internal Insulation and Moisture*, 2011

[8] Annex 4 ARUP, *Windows Integrated Shading Devices*, 2011

ANNEX 1

Passive and Active energy efficiency solutions

P05 - ARUP

European Commission

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Passive and Active energy efficiency solutions

077315-94

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Arup Italia srl
Corso Italia 13
20122 Milano
Italia
www.arup.com

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ARUP

Indice

1 Introduction

Before starting to refurbish an existing building it is fundamental to carry out an analysis of the actual existing building’s performance and condition to understand which areas need to be improved to achieve current benchmarks in term of energy saving, comfort, security and life safety.

A baseline can be established by conducting an audit. This should be carried out as a systematic examination and measurement of key aspects of the building; the main aspects to be considered are energy consumption, occupant satisfaction, facilities management operations, indoor environmental quality, water consumption, waste generation and the necessity to preserve historical parts of the building.

At first, it is important to understand the past of the building with regard to its function and to all the changes brought out during its life from structural, envelope, electrical and mechanical systems point of view.

After the audit it is possible to establish targets and goals and the appropriate level of refurbishment.

The existing building can be classified in terms of building condition and level of refurbishment required; an example of this classification is shown in the picture below.

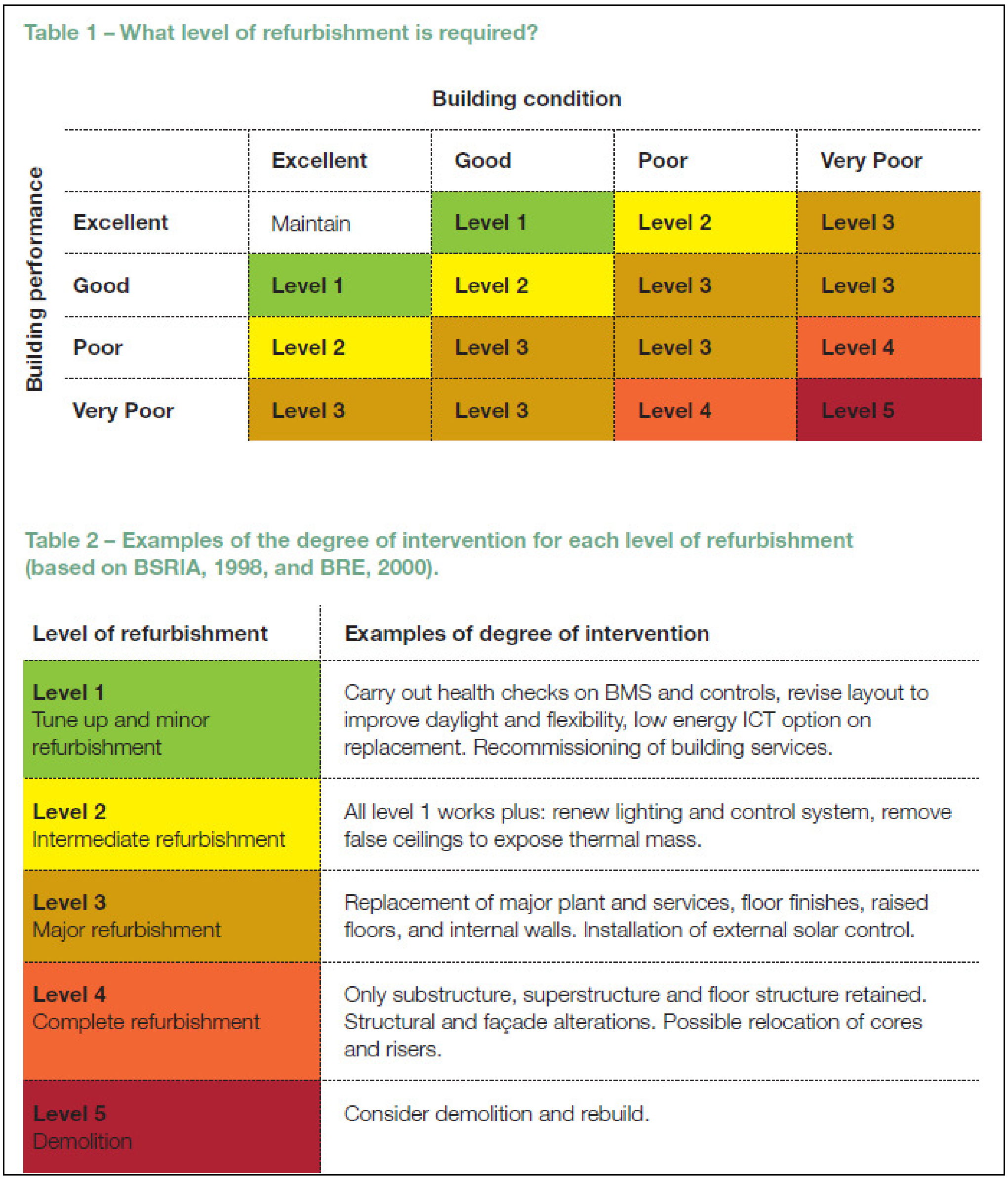

Table 1 – What level of refurbishment is required?

Building performance \ Building condition	Excellent	Good	Poor	Very Poor
Excellent	Maintain	**Level 1**	**Level 2**	**Level 3**
Good	**Level 1**	**Level 2**	**Level 3**	**Level 3**
Poor	**Level 2**	**Level 3**	**Level 3**	**Level 4**
Very Poor	**Level 3**	**Level 3**	**Level 4**	**Level 5**

Table 2 – Examples of the degree of intervention for each level of refurbishment (based on BSRIA, 1998, and BRE, 2000).

Level of refurbishment	Examples of degree of intervention
Level 1 Tune up and minor refurbishment	Carry out health checks on BMS and controls, revise layout to improve daylight and flexibility, low energy ICT option on replacement. Recommissioning of building services.
Level 2 Intermediate refurbishment	All level 1 works plus: renew lighting and control system, remove false ceilings to expose thermal mass.
Level 3 Major refurbishment	Replacement of major plant and services, floor finishes, raised floors, and internal walls. Installation of external solar control.
Level 4 Complete refurbishment	Only substructure, superstructure and floor structure retained. Structural and façade alterations. Possible relocation of cores and risers.
Level 5 Demolition	Consider demolition and rebuild.

Figure 1: Level of refurbishment

In order to achieve good and interesting results from an existing building refurbishment, it is necessary to elaborate a detailed operating programme connected, at first, with passive and then with active strategies and with the use of renewable energies.

Passives strategies are referred to the behaviour of the building without considering mechanical and electrical systems:

- efficiency of the envelope (insulation, thermal mass, airtight);
- optimisation of solar gains (use of greenhouse and solar shading);
- utilisation of day lighting and natural ventilation.

During the design phase, these steps have to be followed:

- reduce demand (energy and water demand);
- maximise efficiency of the existing systems or replace them if it is necessary;
- install and integrate renewable energy systems.

2 Passive systems (Subtask 3.2.10)

2.1 Thermal Mass

The thermal mass of a building can be used to store energy. During warm periods heat will be stored in the thermal mass. When the temperature of the room cools down, the massive structures (for instance exposed concrete walls) will release the stored heat to the room.

To avoid overheating in summer, it is suitable to introduce night cooling in conjunction with exposed thermal mass: night cooling can be used to lower the temperature of the thermal mass of the building when the outside temperature is below the internal daytime design temperature.

An advantage connected with the use of thermal mass is that massive structure allows to delay and to reduce the peak temperature (see picture below)

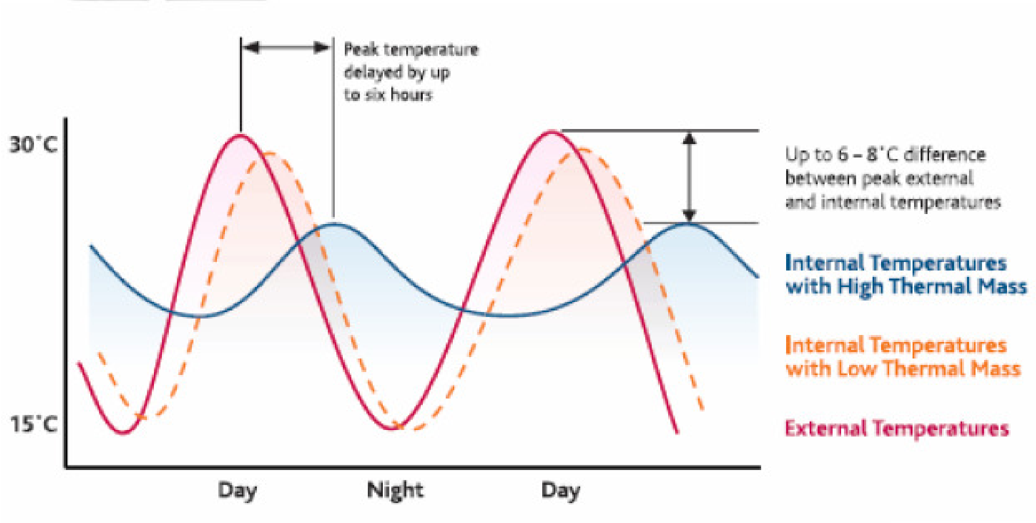

Figure 2 : Thermal Mass

A disadvantage of thermal mass is that it takes longer to heat-up the building and therefore it will use more energy. Whether using thermal mass in the building is energy efficient is therefore determined for a large extent by the heating set point during the night.

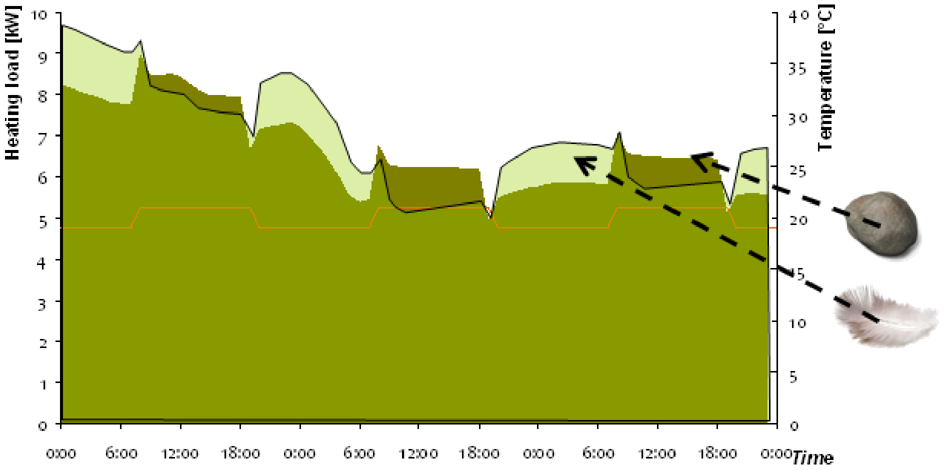

Figure 3: Thermal Mass and heating loads (with continuous occupancy)

This approach depends on the use of the building. In buildings with continuous occupancy and constant set-point temperature, thermal mass can save fuel. This allows the building to cool down overnight or when not occupied. The resulting lower average temperature difference between inside and outside means that, in theory, less fuel is needed.

In type of building without continuous occupancy and variable set-point temperature, thermal mass has to be decrease to avoid the amount of surplus-energy required to heat-up the building.

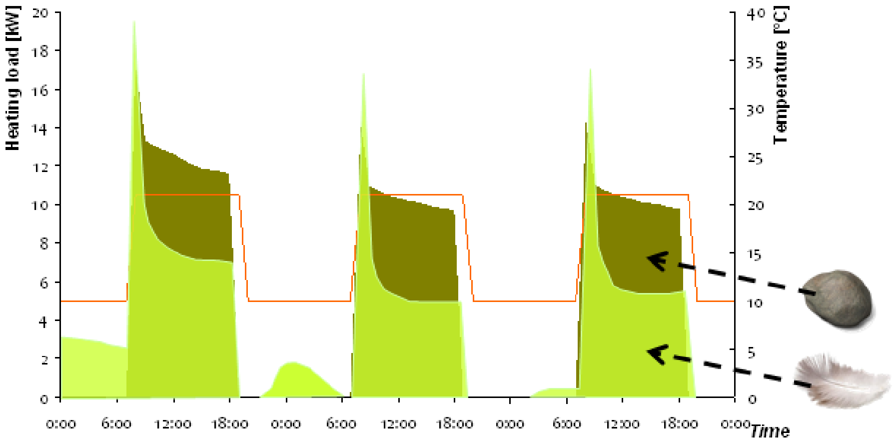

Figure 4: Thermal Mass and heating loads (without continuous occupancy)

This approach can create problems for masonry buildings with high thermal mass, particularly if they are also damp. As the building begins to warm up, surfaces, particularly those most rapidly heated when the heating comes on, begin to evaporate moisture at a high rate, raising the dew point of the air. This may possibly even lead to condensation on the cold structure at points which the heat reaches more slowly. For example, in intermittently heated churches with warm air systems, the floors sometimes become damp shortly after the heating starts.

As this process is repeated, the effect is to distil moisture from the warmer to the colder parts of the building. This is most likely to affect windows, roof spaces, ‘cold bridges’, window reveals, the corners of rooms, behind cupboards and places where insulation stops.

The second problem with intermittent heating is that, to offset the ‘cold radiation’ from the unheated masonry structure, the air has to be hotter than normal to provide the same degree of comfort. The rapid changes in air temperature and humidity can also cause damage to decorated surfaces. There can be major problems where salts are present, as these can re-crystallise as conditions fluctuate. This can lead to accelerated deterioration of the fabric and the rapid loss of historically and aesthetically important surfaces such as stone carvings and wall paintings.

Buildings with high thermal mass are generally better heated continuously to a low level, or with night set back. This can sometimes also prove more economical. Occasionally, the use of a building is so low that full heating cannot be justified. Here, one might consider increasing the thermal comfort locally, for instance with underfloor heating.

2.1.1 Phase Change Materials

It would also be possible to use Phase Change Materials (PCM) for existing building with light envelope (ex: wood wall, light thickness brick wall).

They will allow achieving performance similar to thermal mass building with small thickness layers.

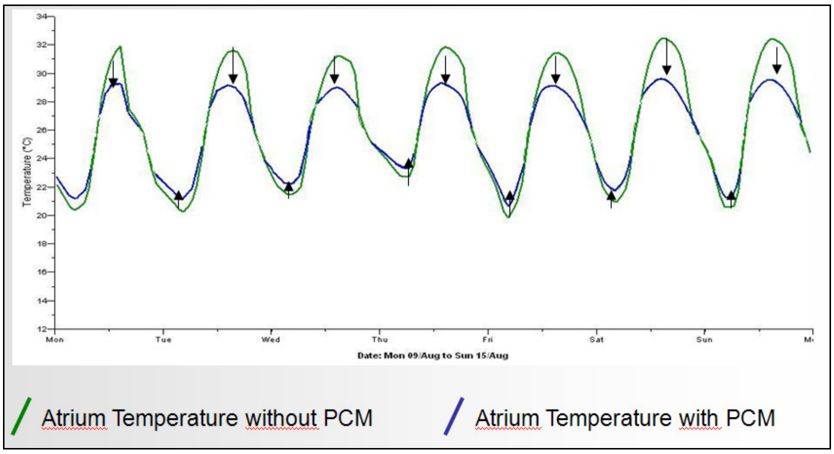

Figure 5: Effect of PCM on temperature profile for an atrium

2.1.2 Green roofs

Green roofs are vegetated layers that sit on top of the conventional roof surfaces of a building. Because of their thermal benefits, their ability and their value in promoting biodiversity, green roofs have come to be important elements of sustainable and green construction in many countries. Their visibility can give a very positive and distinctive image to a building.

Integrating green roofs in existing architecture has many advantages:

- reduction of the heat-island effect;

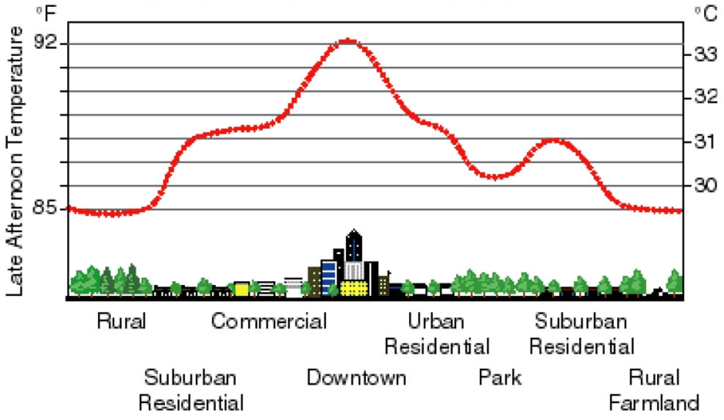

Figure 6: Urban Heat Island Profile (Source: The Met Office)

- increase of roof thermal mass and insulation;
- decrease of peak rainwater runoff from roofs; useful to combat flood risk;
- increase of the lifespan of the building materials (waterproofing and insulation layers) thanks to reduction of temperature fluctuations on the roof surface
- green roofs absorb a small amount of carbon from the atmosphere;

It is necessary to pay attention to replace a traditional roof with a green roof with regard to the roof structure that has to be characterized by an adequate carrying capacity because of the weight of the ground especially when it’s wet.
For this reason it is suitable to use plats like sedum that requires few quantity of ground (7-8 cm). This kind of culture requires also less maintenance operation than grass or other type of plants.

Figure 7: Examples of green roofs

2.1.3 Greenhouse

The greenhouses can be used as a buffer zone during winter because, thanks to solar gains, the temperature of the greenhouse will be higher then outdoor; in this way the heat losses through the building envelope can be reduced significantly. In summer to avoid overheating, solar shading and natural ventilation, opening windows, have to be provided.
In an existing building could be not so difficult to create a sort of green house, maybe closing existing terraces with glazing surfaces that in summer can be totally opened.

3 Active energy efficiency solutions (Subtask 3.2.11)

The most common “actives strategies” are:

- use of high efficiency systems such as condensing boiler, heat pumps, geothermal and heat recovery system, equipments like radiant panels or chilled beams that work with low water temperature and that are able to guarantee high comfort level;
- use of renewable energies (wind, sun);
- advanced automatic control systems;
- efficient water management.

Generally before starting refurbishment activities it has to be considered the following points.

- Building services are normally designed to suit people and processes instead for existing buildings, it is often very important to consider also the building itself. For example, a precise control of the heating to regulate relative humidity could be less fundamental to achieve comfort but could be very important for building conservation.
- Sometimes the building services of a historic structure can have themselves a historic interest; in this case this options are possible for these systems:
  - remain in use unaltered;
  - be refurbished and re-used;
  - be left for visual effect or for historic reasons but be functionally replaced.
- In the last years a lot of new regulations connected with energy saving and safety has been passed; after a refurbishment, the building has to follow them (except particular situation).
- Most historic buildings have changed function since they were built.
- Generally existing buildings are formed in a way that suites the local climate, but today could be totally inadequate also because of the climate changes.

For these reasons, each building has to be examine analysing vantages and advantages connected with different design options to find out the best one.

For instance, with regard to HVAC system, it is common to evaluate the following KPI (key performance indicators) to choose the most suitable solution.

Quality

- Temperature, humidity and air velocity control to achieve comfort and to conserve building.
- Local control.
- Speed and accuracy of control.
- Air quality required that it is connected with the function of the building and with the actual regulations.
- Noise level.
- Reliability.
- Adaptability and flexibility.
- Beauty: systems integration it is always important and become fundamental for historical buildings.

Cost

- Space take: during a refurbishment it is not easy to find space to install new systems; sometimes could be possible to split high space (creating a mezzanine floor) and obtain more exploitable areas.
- Capital cost.
- Environmental cost.
- Operating cost.

Time

- Ease of installation.
- Ease of commissioning.
- Ease of Maintenance.
- Lifespan Central Plant.
- Lifespan Terminal Units.

Not all these parameters have the same importance, the hierarchy is related to the building function (for instance reduce the noise level could be more important in a hotel than in a shopping mall) and, for a refurbishment, some parameters, strictly related to the building conservation, will be taken into account more than other connected, for instance, with comfort and energy saving.

A typical example is the control of temperature and humidity in an old building where an accurate control of these parameters could be not so fundamental for occupants comfort but it can be necessary to avoid damages of ancient structures or internal furniture.

Cycles of rising and falling relative humidity can be very damaging, by causing re-crystallisation of salts and for objects made of mixed materials which expand and contract at different rates. If a building does not have to be heated for comfort, is of significant historic value and contains fixtures, fittings or contents that are sensitive to changes in moisture content, then one should consider the option of controlling the heating to keep relative humidity within a relatively narrow range.

This is a common procedure of the English National Trust. Set-points can be:

- relative humidity set point between 50 and 65%,depending on the conditions to which the building has acclimatised;
- alarming set-points at 40 and 75%;
- minimum room temperature 5°C; and
- maximum room temperature for heating: 18°C in winter and 22°C from April to October.

There is often also a lower temperature limit to protect the building against freezing.
Conservation heating provides useful protection for objects and for the fabric of the building. It is particularly useful in storage areas and in buildings that are closed to the public in winter, where temperatures of about 10°C may be required.

3.1 Existing systems

Old existing heating/cooling systems with related equipments (fans, pumps) are often characterized by:

- high energy consumption;
- air pollution generation;
- thermal losses mostly regarding the distribution system (inefficient insulation of pipes and ducts);
- manual or automatic but not precise and efficient regulation systems;
- not easy integration with renewable energies;
- high noise level;
- unsafely;
- not correctly sized.

During refurbishment operations all the single equipments have to be analysed to

find the way to create a whole efficient system.

3.2 Generation systems

Replacing existing generator system can make a relevant difference and significantly increase the energy efficiency of a building. The old boiler could be replaced with one with a higher efficiency, for instance a condensing boiler, or with a heat pump. Another solution could be choose a new generator that could be feed with renewable energy (biomass, wind or solar energy)

Considering the same energy demand, the adoption of this solution helps to reduce primary energy consumption and $C0_2$ emissions, and it allow a sensible reduction of operating costs.

In some countries, like in Italy, there is also the possibility to obtain fiscal deductions for the replacing of the old generator with another one with higher efficiency.

3.2.1 Boilers

To increase the efficiency of the hot water generator it is suitable to use condensing boilers that use the part of available heat (condensation heat) that would otherwise be lost; in this case the boiler efficiency is more than 90% and can be increased if the water average temperature is close to 35°C.
Another solution to save energy is to use modulating burners or modular boilers
A regular boiler maintenance programme can minimize NOx, CO and CO2 emissions from boilers.
A boiler flue has to be the minimal visual impact; a solution could be to place the flue inside an old chimney stack, using for instance special rounded inox ducts.

3.2.1.1 Biomass

As alternative to the traditional fuels (hydrocarbons like methane and diesel fuel) biomass can be used. Biomass involves generating energy from organic matter for instance woodchip, wood pellets or biogas, (derived from the breaking down of organic materials).
Before deciding to install a biomass generator it is fundamental:

- to be sure of the availability of the materials used like fuel;
- to have enough space available for biomass storage;
- to have the guarantee of fuel supply and fixed price for a set number of years.

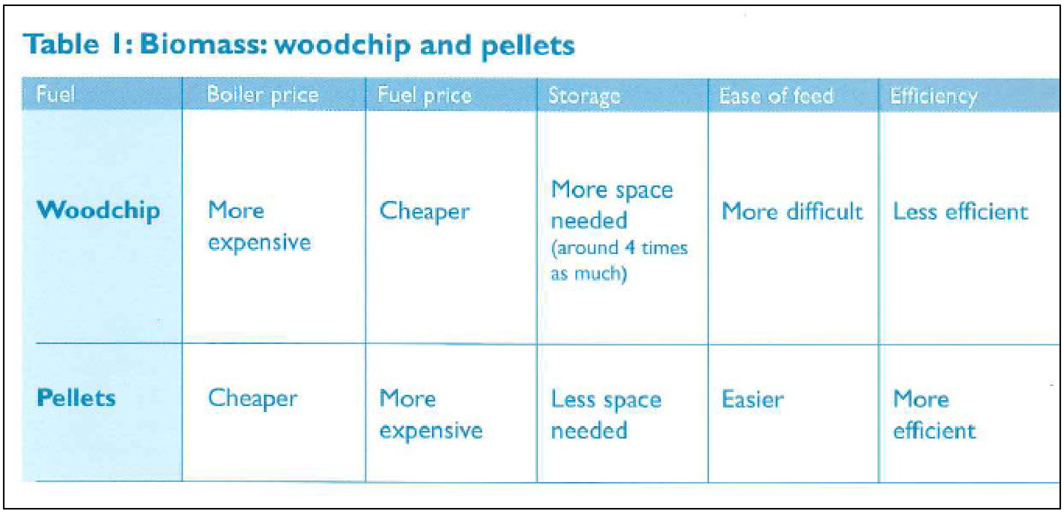

Table 1: Biomass: woodchip and pellets

Fuel	Boiler price	Fuel price	Storage	Ease of feed	Efficiency
Woodchip	More expensive	Cheaper	More space needed (around 4 times as much)	More difficult	Less efficient
Pellets	Cheaper	More expensive	Less space needed	Easier	More efficient

Figure 8: Biomass- woodchip and pellets[1]

3.2.2 Chillers and Heat Pumps

The main advantages of heat pumps compared with boilers are:

- more primary energy saving in particular if combined with well insulated and air tight building and low water temperature emission systems (under floor heating or chilled beams);
- some heat pumps, used for heating in winter , can be reversed to provide cooling during summer.

Pay attention to potential pollution due to refrigerant: prefer Zero ODP (ozone depletion potential) for example HFC.
A heat pump needs a thermal source for the heat exchange; this source can be air, water (sea, lake, river, and groundwater) or ground.
The main differences between air heat pumps (AHP) and water heats pumps (WHP) are shown in the table below.

	Thermal source		**Notes**
	AIR (AHP)	**WATER (WHP)**	
Noise		√	• AHP are generally characterize by higher noise level; but it has to considered that also cooling towers combined with WHP can be noisy.
Technical space requirements	√		• WHP need more space because of the presence of more pumping stations. • With regard to WHP, the space requirements increase if they are combined with cooling towers.
Flexibility		√	• WHP can be installed also inside the building into closed rooms.
Installation cost	√		• WPH has a higher installation cost due to plumping, filtering and piping of water for the heat exchange.
Efficiency and operating cost		√	• WHP is characterize by higher efficiency due a more constant temperature of the thermal source.

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[1] “The Green Guide for Historic Buildings: how to improve the environmental performance of listed and historic buildings by”-The Prince’s regenerations trust, March 2010

Ground source heat pumps can be combined with this type of heat exchangers:

- vertical boreholes (typical depth 100-150 metres);
- horizontal pipes loop;
- energy pillars (not applicable for a refurbishment).

Vertical boreholes are more efficient and need a smaller installation area compared with horizontal heat exchangers, but they are more expensive because of the depth of the excavation.

Before decide to install geothermal heat pump it is necessary to study the site geological condition to esteem the thermal performance of the ground (“ground response test”) and the correct drilling techniques (important to find out the level of the water table).

3.2.3 Solar thermal

The function of solar thermal collectors is to produce hot water that can be used for sanitary purposes or to feed heating systems. This last option is not always convenient; this depends on climate of the building site, on the emission heating system (low water temperature systems are in this case favoured) and on the efficiency of the envelope.

It is possible to choose between two type of solar collector that are characterized by different efficiency and construction: flat plate collectors and evacuated tubes solar collectors; the fist ones are more cheap and less fragile.

Solar collectors can be fitted on the top of the roof or be flush fitted to replace the roof surface.

Use of solar thermal systems is not always allowed because of the visual impact of the collectors; other times sometimes it is no possible to install them on the roof, due to lack of space (or lack of surfaces with the right orientation).

In these cases, in some countries, like in Italy, it is necessary to find another way to satisfy the 50% of sanitary hot water demand with renewable energies.

It is important to consider that to install a solar systems requires space on the roof but also inside (or close to) the building because of the necessity to storage hot water produced in a tank (50-70 l/ for each flat plate collector square metre)

3.2.4 Combined systems (electricity + heating)

Combined systems (CHP) are able to capture waste heat produced during power generation and reuse it to heat building.

For cooling purpose, these systems can be combined with absorption chillers that use the heat to produce chilled water.

The efficiency of these systems increase with the increasing of system dimensions and if a continuous running is performed. A lot of times these systems are feed using waste or biomass.

3.2.5 Connection with distric heating

A district heating consist in one or more central plant, generally located in a sub urban zone, that provide thermal Energy, for heating and hot water, through a underground pipe line; an heat exchanger, connected with this pipe line, is installed in each building.

This system solves most of the problems related to other traditional systems and it is characterized by advantages in terms of :

- safety, because of the lack of fuel and flames in the building;
- maintenance and reliability ;
- techinal space requirements;
- energy saving.

3.3 Ventilation systems

Ventilation is important to guarantee the adequate air quality and the absence of condensation phenomenas. In the past only not controlled natural ventilation (opening window) was foreseen today natural ventilation can be controlled using automatic devices connected to windows with opening regulated for instance by temperature sensors. If natural ventilation is not enough or it is not possible (for instance because of noisy outside environment), it can be combined with mechanical ventilation (hybrid ventilation).

To achieve energy saving it is suggested to provide a centralized ventilation system and it is necessary to use an efficient heat recovery systems that transfer heat between inbound and outgoing air flow streams, reducing the heating (or cooling) demands of the inbound air

Other suitable solutions are the following:

- use of freecooling in particular in the middle seasons. Freecooling is often used when ventilation is provided by displacement systems;
- check and repair, if necessary any ductwork leakage; ductwork leakage increases the amount of energy needed to meet indoor air conditions, and reduces indoor air quality;
- use of occupancy sensor or switch control to ensure that air conditioning systems do not operate needlessly;
- introduce demand control ventilation involves monitoring carbon dioxide levels in the air and varying ventilation rates proportionally. In this way, outside air rates are matched to actual occupancy densities, rather than on assumed occupancy patterns

3.4 Heating and cooling distribution system

With regard to heating and cooling distribution system in an existing bulding, it is fundamental to review ductwork and pipe work insulation: insulation reduces the amount of energy lost in duct and piping systems.

A key issues in the current practice is fitting and replacement of services installations that must be done avoiding unnecessary damage to the historic fabric by short-lived services elements and observing the principles of reversibility and minimum intervention. This relates not only to holes and fixings, but also to the direct and indirect damage to historic objects by the proximity of services, for example by:

- covering up or interrupting the view of important features and details;
- passing too close to important surfaces which might be consequentially damaged in the course of the work or in use;
- staining by patterns of heat and air movement;
- disturbance of the heat and moisture balance leading, for example, to crystallisation of salts in walls and damage to details and surface finishes.

Constraints of this kind may affect the choice of options and consequently their energy efficiency levels. For example, it might not be possible to replace a conventionally-flued heater with a more efficient balanced-flue version because of the destruction caused by the hole, the visual appearance of the outdoor terminal, or the technical risks of disturbing a rubble-filled wall.

Another important issue is the analysis of the heating and cooling emission systems: old systems such as radiators could be replaced with more efficient equipment such as radiant panel or chilled beams. In this case it is necessary to study the interaction of these solutions with the rest of building; in particular in the old building suspended ceiling or void floor are not present and it’s not possible to create them, so is quite difficult to hide, integrate or and find technical spaces for mechanical and electrical services .

To resolve space problems connected with refurbishment of an emission system, some manufactures have create particular under floor heating systems (see images below) that allow to install the new systems directly on the old floor and that, with the help of metal thermal diffusers, allow to realized a under floor heating package only in few centimetres.

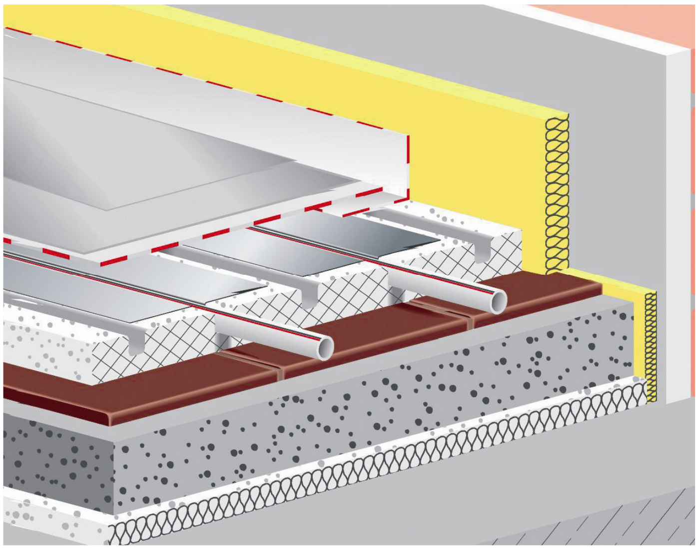

Figure 9: Underfloor heating system for refurbishment (Source:Velta)

Sometimes, to reduce technical spaces required for services, in particular for air ducts, and reduce energy consumption, related to the fans, it could be used a variable air volume systems.
Another option to reduce the energy consumption and increase comfort is to use a displacement system combined, in winter, with perimeter heating in particular close to glazing surfaces.

3.5 Automatic control/ regulation systems and BMS

To achieve comfort, safety and energy saving, it is fundamental to install an adequate automatic control e regulation:

- timers and thermostat should be installed to ensure that energy for heating and cooling is only used when required;
- thermostatic valvels on the radiators;
- compensators could be used to regulate temperature according weather conditions;
- provide digital control system to monitor and control all major plant: digital control systems can control and modify flow rates, compressors, pumps, fans, valves, etc. A digital system will ensure accurate and efficient use of equipment;
- provide sub-metering of electricity , gas and water.

3.6 Sustainability in operation

The operating costs of building are higher than the initial costs to build the building.
This is why this phase is extremely important to create truly sustainable buildings.
This can be achieved by:

- reducing the energy consumption;
- use efficient metering and control systems;
- reduce the consumption of materials;

- using sustainable technologies which are easy to replace;
- use of replaceable elements.
- waste management
- implement a comprehensive preventative maintenance program: a comprehensive maintenance program ensures that equipment works at as efficiently as possible, extends the life of equipment, and reduces operating costs and energy use

3.6.1 Equipment

- Time switches or similar on small equipment to switch off automatically after a period of time when they are not used; this suggestion reducing unnecessary energy usage.
- Introduce variable speed pumps and fans : variable speed works by decreasing power to pumps and fans to decrease flow rates to match decreased loads.
- Replace the oldest devices and equipments with others with a higher energy classification.

3.7 Adaptation to climate change

To ensure that buildings are able to adapt to future climate changes, has to be taken into consideration the following possibilities

- Minimize dependence on exhaustible sources of energy: (oil, natural Gas, Coal, Uranium) .

- Design systems able to achieve the required performances also with extreme weather (hotter dryer summer; warmer wetter winters); reduce the risk of overheating due to the global warming and incorporate cooling systems on all the buildings.

- Ensure adequate drainage from the site to avoid problems of due to heavy downpours, storms: help the building to deal with large volume of rain increasing the diameter of gutters and down pipes or providing green roof and increasing permeable surfaces on site.

3.8 Water management

The first solution to optimize the water management is to reduce water demand with the help of:

- toilets with cistern and dual flush;

- low-flow showers;

- sanitary fixtures time controlled or combined with sensor , to avoid excess of water use in particular in the public toilets;

- install waterless urinals (used in the office could save up to 30% of the water used);

Figure 10

- provide, for lavatory sinks and showers sinks, simple devices that mix water flow rate with air (figure 10); this option is interesting because could be improved also without changing the sanitary fixtures;
- efficient irrigation systems and cultivation of native and site adapted plants.

A lot of water requirement could be met using non-potable water such as flushing toilets, irrigations- (with regard to typical residential water consumption, see picture below); this water can be recovered by:

- collecting and reusing, after adequate filtration process , rain water;
- collecting and reusing, after adequate filtration process , grey water;

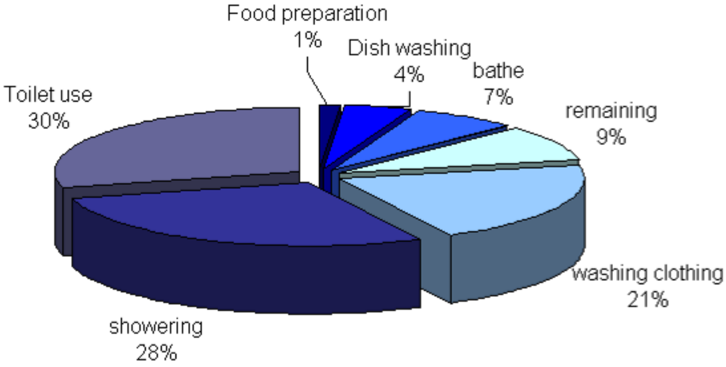

Figure 11: Typical water consumption (residential buildings)

3.9 Case study

3.9.1 39 Hunter Street,Sydney, Australia

39 Hunter Street is a seven storey, 6,000sqm office building built in 1916. As a result of substantial refurbishment, it is the first heritage-listed building in Australia to achieve a 6 star Green Star Office Design rating (figure 12).

Figure 12

The key initiatives are the described in the following points.

- A new central atrium maximising natural light to the floor plates.
- Displacement air-conditioning.
- Energy efficient lighting controls, high efficiency luminaires with high frequency ballasts and low energy lamps.
- The sprinkler system tank is used for thermal storage.
- Fire system test water is stored and run on a closed loop.
- A peak load reduction strategy that included gas fired generators to run one of two chillers.
- Rain water is collected and re-used, and all storm water leaving the site is treated and filtered by a leaf filter system. Outflow to the sewer system has been reduced by 40% by recycling.

3.10 Conclusions

Much advice is available in CIBSE Guide F (1998), and in the publications of the Energy Efficiency Best Practice programme. More relevant detailed advice on strategies, equipment and installation is expected to be included in *Energy efficient building services and fabric for historic building: a good practice guide for historic and traditional buildings (CIBSE)*.

The following picture shows an example of a cost effectiveness analysis[2].

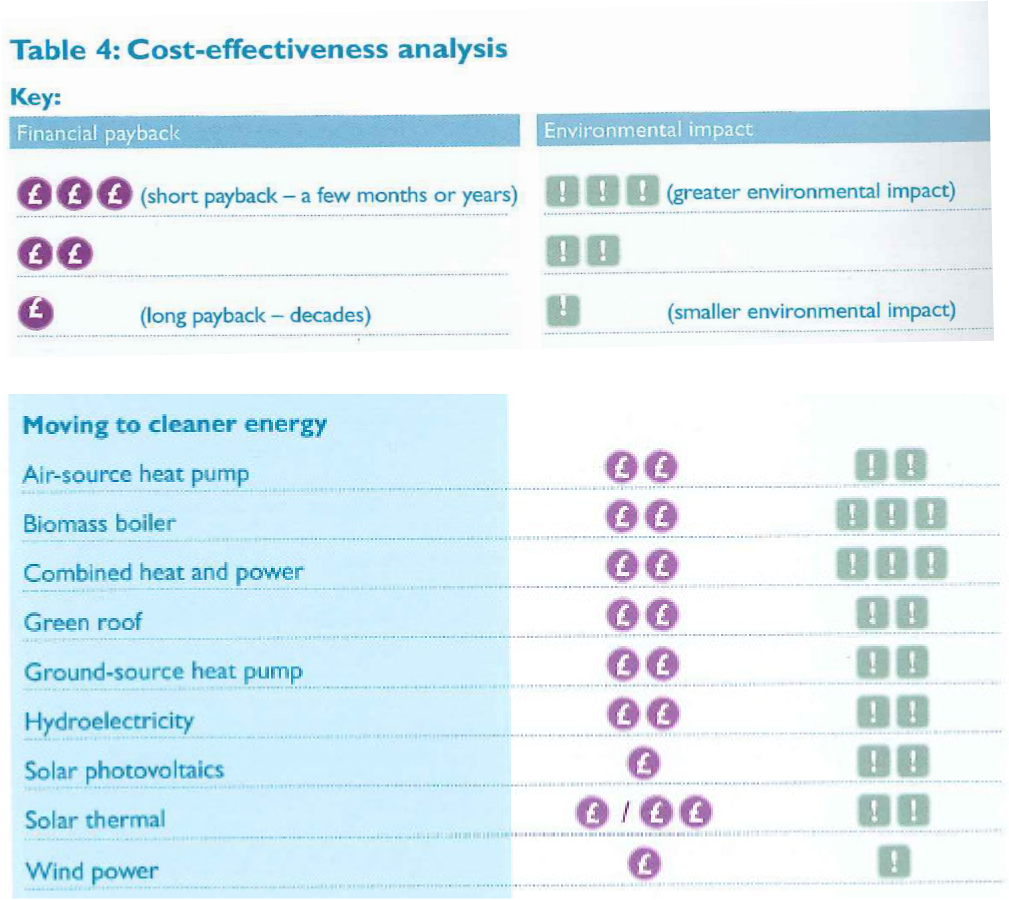

Table 4: Cost-effectiveness analysis

Key:

Financial payback	Environmental impact
£££ (short payback – a few months or years)	!!! (greater environmental impact)
££	!!
£ (long payback – decades)	! (smaller environmental impact)

Moving to cleaner energy		
Air-source heat pump	££	!!
Biomass boiler	££	!!!
Combined heat and power	££	!!!
Green roof	££	!!
Ground-source heat pump	££	!!
Hydroelectricity	££	!!
Solar photovoltaics	£	!!
Solar thermal	£ / ££	!!
Wind power	£	!

Figure 13: Cost effectiveness analysis

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[2] The green guide for historic buildings: how to improve the environmental performance of listed and historic building, Prince's Regeneration Trust, March 2010.

3.11 Open issues and guidelines for the project

- Production of a list that resumes all the main controls which should be carry out on the existing systems before starting a refurbishment and which are the most important devices and equipments that should be checked (generators, pumps, fans, piping insulation, etc.)
- Investigate the interaction with passive and actives strategies (for instance natural ventilation with mechanical ventilation).
- Find out modern high efficiency systems and technologies that can be easily used in an existing building without causing damages.
- Investigate in which cases it is possible not totally replace the existing systems but to make them more efficient and suitable to be integrated with removable energy systems.

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ANNEX 2

RES Integration

P05 - ARUP

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RES integration

077315-94

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Arup Italia srl
Corso Italia 13
20122 Milano
Italia
www.arup.com

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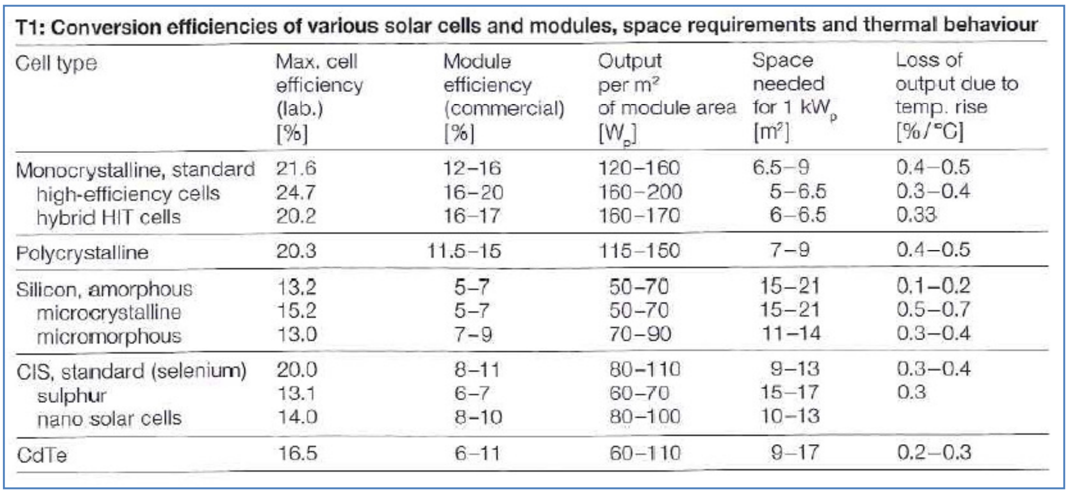
ARUP

Indice

1 BIPV

1.1 PV materials and cells

Possible PV materials and cells are reported below.



T1: Conversion efficiencies of various solar cells and modules, space requirements and thermal behaviour

Cell type	Max. cell efficiency (lab.) [%]	Module efficiency (commercial) [%]	Output per m² of module area [W_p]	Space needed for 1 kW_p [m²]	Loss of output due to temp. rise [%/°C]
Monocrystalline, standard	21.6	12–16	120–160	6.5–9	0.4–0.5
high-efficiency cells	24.7	16–20	160–200	5–6.5	0.3–0.4
hybrid HIT cells	20.2	16–17	160–170	6–6.5	0.33
Polycrystalline	20.3	11.5–15	115–150	7–9	0.4–0.5
Silicon, amorphous	13.2	5–7	50–70	15–21	0.1–0.2
microcrystalline	15.2	5–7	50–70	15–21	0.5–0.7
micromorphous	13.0	7–9	70–90	11–14	0.3–0.4
CIS, standard (selenium)	20.0	8–11	80–110	9–13	0.3–0.4
sulphur	13.1	6–7	60–70	15–17	0.3
nano solar cells	14.0	8–10	80–100	10–13	
CdTe	16.5	6–11	60–110	9–17	0.2–0.3

Figure 1: Conversion efficiencies (source: Detail, Practice-Photovoltaics)

In the following section a very brief description of each typology is reported. Possible suppliers and product manufacturers are listed to provide feasibility examples currently available.

1.1.1 Monocrystalline

Monochrystalline silicone cells are usually manufactured from a single crystal ingot of high purity, most commonly grown by the Czochralski method (crucible drawing process). The diameters are 12.5 or 15 cm (4 or 5 inches). The ingot is cut into thin slices which are processed to make PV cells. The circular shape is cut away for better packing into a module. Depending on how much of the monocrystal is removed, the range of cell shapes produced can be round, semi-round or square.

Figure 2: The G8 “solar showcase” BIPV pavilion built in 1998. This close-up shows the outline of monocrystalline cells within the modules. Photo: Christian Richters.

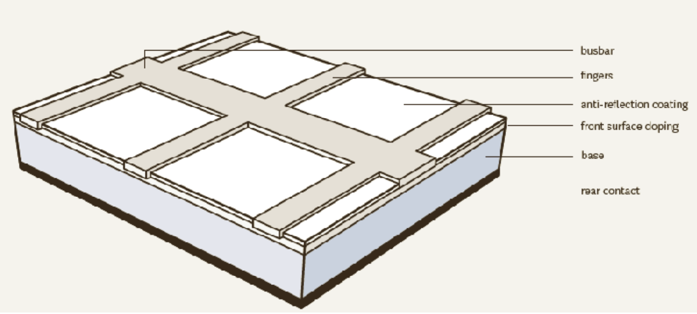


Figure 3: Schematic view onto the top of crystalline silicon cell showing the patterning of the top metallisation grid and the layers beneath.

1.1.2 Polychristalline

An alternative way of making silicon PV cells is from polycrystalline silicon (also known as multicrystalline silicon). The starting material is melted and cast in a cuboid form. As the silicon solidifies, large crystals are formed with grain sizes from a few millimetres to a few centimetres. The grain boundaries reduce the efficiency slightly. The ingot is cut into bars and then sliced into thin wafers that are used to make the cells, similar to the completion of single crystal cells. Polycrystalline silicon is slightly less expensive than monocrystalline silicon but also slightly less efficient. There is a trend to larger cells of 21 × 21 cm (8 inch square) for lower costs and higher overall module efficiency.

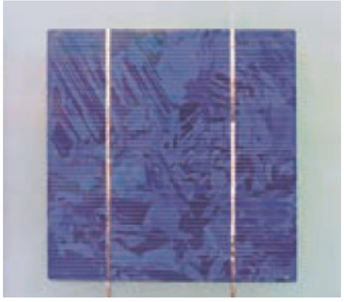


Figure 4: An individual polycrystalline silicon cell showing two busbars. Photo: Frank P. Palmer

1.1.3 Thin film

Thin-film cells are constructed by depositing extremely thin layers of PV materials onto a superstrate, the front glass, or onto a substrate, the module backside.
Connections between the cells are an integral part of the cell fabrication so the PV module is made at the same time. Amorphous silicon, copper indium diselenide (CIS) and cadmium telluride (CdTe) are used as the active semiconductor materials. Compared to manufacturing temperatures of up to 1500°C for crystalline silicon cells, thin-film cells require deposition temperatures of between 200°C and 600°C. The lower material and energy consumption and capability for high automation of module production offer considerable cost savings. However the efficiency is lower than for crystalline silicon technology. The lower efficiency means that a larger area is required to achieve the desired power.

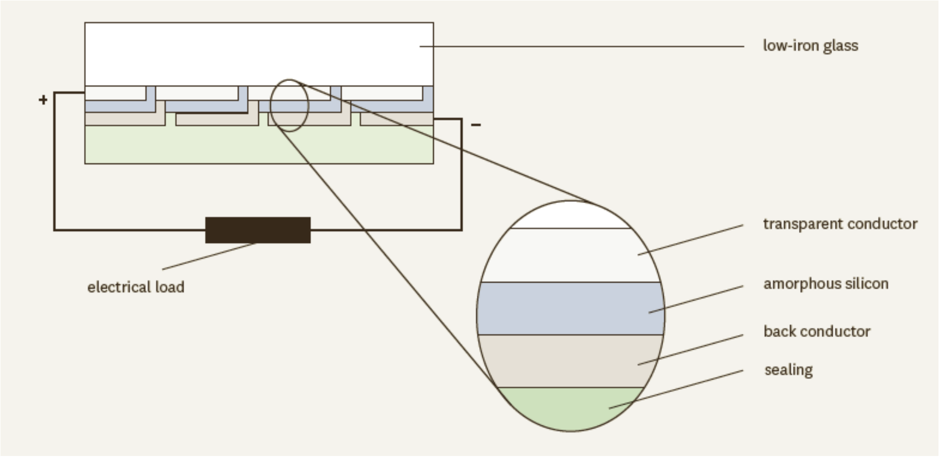
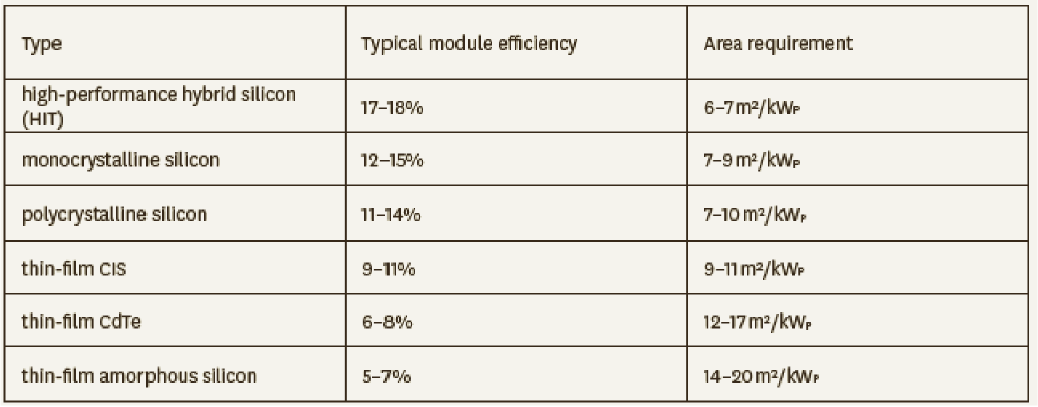


Figure 5: Schematic cross section of a thin-film silicon module of four cells. The thickness of the active layers has been exaggerated to show how the electrical connection between adjacent cells is formed.

CdTe thin-film modules are made in a similar way to amorphous silicon onto a glass superstrate. CdTe modules have the lowest production costs among the current thin-film technologies. Although cadmium is a heavy metal with environmental issues, the chemical form as CdTe is a very stable, non-toxic compound. Furthermore manufacturers take back these modules at the end of the life for controlled recycling.
CIS thin-film modules are normally fabricated onto a substrate, the back face, from the bottom up. The appearance is virtually black. Substrates can be glass, metal or plastic. Unlike amorphous silicon, CIS cells are not susceptible to light-induced degradation in performance.



Type	Typical module efficiency	Area requirement
high-performance hybrid silicon (HIT)	17–18%	6–7 m^2/kW_P
monocrystalline silicon	12–15%	7–9 m^2/kW_P
polycrystalline silicon	11–14%	7–10 m^2/kW_P
thin-film CIS	9–11%	9–11 m^2/kW_P
thin-film CdTe	6–8%	12–17 m^2/kW_P
thin-film amorphous silicon	5–7%	14–20 m^2/kW_P

1.1.3.1 Schott

ASI Glass PV modules are based on progressive thin-film amorphous silicon technology that enables a large design variety, from opaque to semi-transparent, max. 30% performance compared to opaque, (see image below: Primary School, Munich, a-Si thin film) and many colours (performance in relating light frequency is smaller compared to black modules) in laminates or double glazed units. Schott offers a system in which the PV modules are taken back and disposed off at the end of their life cycle.

Size

Standard dimensions for a laminated PV module are width 1122 mm and height 690 mm, height can be cut every 16 mm. Minimum module size is approximately 700 x 400 mm.

Performance guarantee

The total energy output that can be achieved depends on the solar power module's location and in which direction it is facing.

The modules are composed out of thin-film amorphous silicon on a superstrate of glass, with typical module efficiency 5-7%. Approx. 14-20 m² are required to generate a kW electricity.

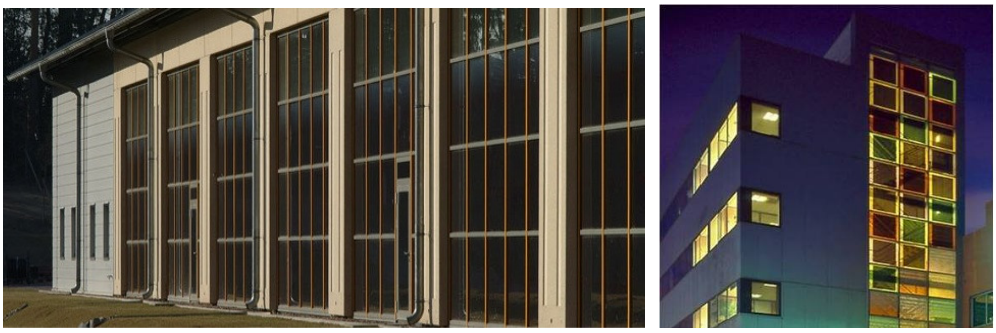


Figure 6: Architectural integration of amorphous silicon cells (Schott)

1.1.3.2 Odersun

Odersun specialises in BiPV applications in custom sizes and shapes and offers a range of preconfigured standardized solar modules for on-roof application as well. The thin-film CIS technology enables the shape and size variety and can be applied in laminates of glass, foils and a combination of both. The technology, using copper bands for the thin-film, is currently developed, but not implemented yet. A cooperating glass manufacturer has to be found still.

Size

Standard PV modules are rectangular, 1000 x 1700 mm^2. Dimensions and shape for customised BiPV can be optimised. The length of the cells can vary from 160 mm to 1250 mm.

Performance guarantee

The modules are composed out of thin-film CIS on a substrate of glass, with typical module efficiency 9—11%. Approx. 9—11 m^2 are required to generate a kW electricity.

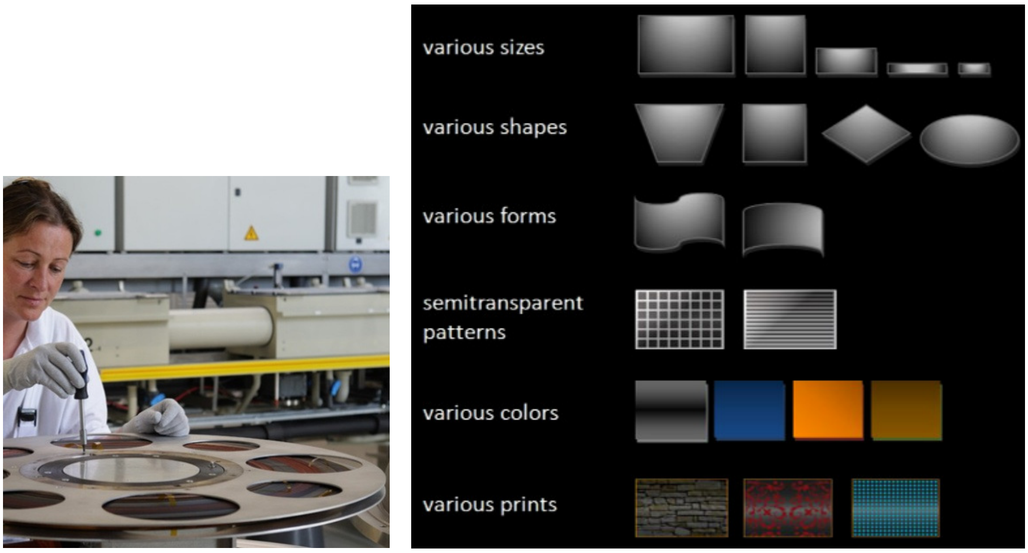


Figure 7: Architectural integration of CIS thin film cells (Odersun)

1.1.3.3 Sulfur Cells

Sulfurcell in Berlin developes thin-film solar facade cassettes for rain screens based on CIS technology since 2003. The origin of the company lies in the Hahn-Meitner-Institut, a research institute on thin-film photovoltaic. The standard modules are available framed and frameless, laminated on a glass substrate and an EVA plastic and glass superstrate. The modules are available in black only.

Figure 8: Architectural integration of CIS thin film cassette system (Sulfurcell)

<u>Size</u>
Standard size of the modules is 1250 x 650 mm. No customized dimensions possible.
<u>Performance guarantee</u>
Sulfurcell provides a 10-year guarantee on 90 % and a 20-year guarantee on 80% of the electric power. Frameless module efficiency is up to 8 %. Typically. 9—11 m² are required to generate a kW electricity.

1.1.4 High Performance PV cells

There are a wide range of new PV technologies being researched and developed. One type to mention here, already well established in production, is the HIT PV cell, which stands for “heterojunction with intrinsic thin-layer”. HIT is a hybrid construction being a combination of a crystalline and thin-film Silicon cell. Amorphous silicon is coated onto both front and rear faces of a monocrystalline silicon wafer. Compared to monocrystalline silicon, HIT cells are more efficient and have less degradation of efficiency with increase in operating temperature.

In a bifacial PV cell, the back surface of the cell is processed in the same way as the front so as to absorb light. Bifacial PV cells are assembled into glass-glass laminates so that these modules allow effective use of the front and rear sides to generate at least 10% more electricity than the standard mono-facial type.

This technology can be used in vertical installations, such as roadside sound barriers, where the sun illuminates both sides through the day. In a building application, the back side can benefit from ambient and reflected light so maximum gain is achieved with reflective or white objects behind. Bifacial transmit more infrared than monofacial cells so benefit from a lower operating temperature.

1.1.5 Cutting edge technologies

1.1.5.1 Integrated PV blinds

Pythagoras Solar is a newly established (2007) firm active in the BIPV market. They offer a transparent and high-density BIPV solution, which combines solar PV power generation with the modularity and insulating benefits of the standard insulating glass unit (IGU). It also prevents direct solar radiation from entering the building.

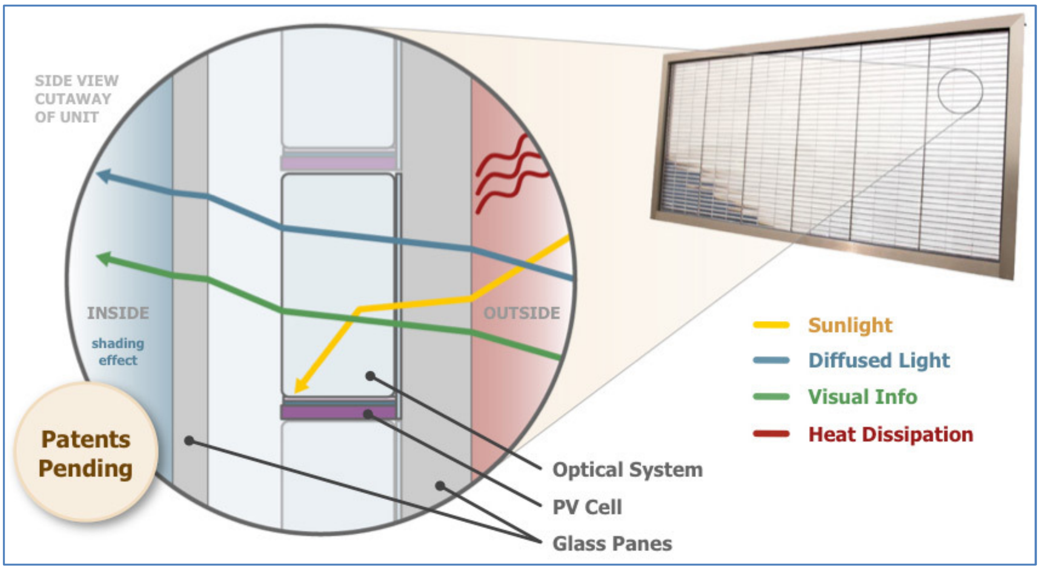


Figure 9: Schemes showing the concept of Phytagors BIPV solution (source: Pythagoras)

Photovoltaics cells are integrated in the cavity of the IGU an act as slat shading device. In fact this integrates horizontal strips of crystalline silicon cells and directs/corrects incoming solar radiation via plastic prisms between the PV strips.

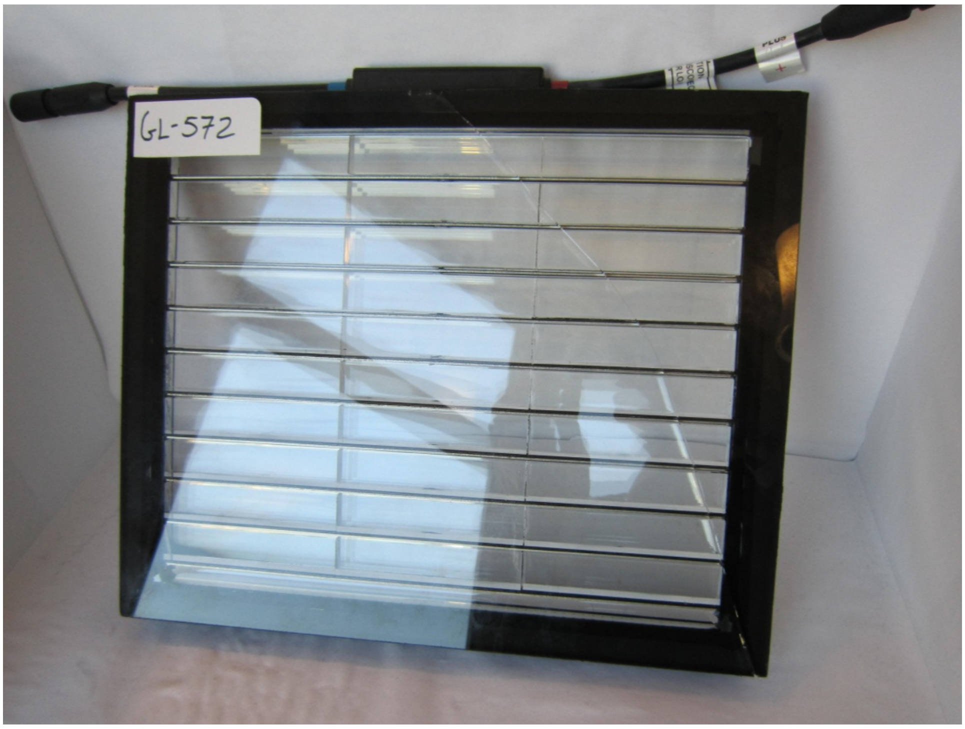


Figure 10: Sample of Phytagors BIPV solution (source: Pythagoras)

The first Pythagoras Solar products are designed for vertical curtain wall and skylight applications and can be optimized for elevation, location, and climate zone.

1.1.5.2 Schott ASi THRU semi-transparent thin film

Some of the most advanced products on the market are semi-transparent, thus providing daylight; however a closer view would show cells subdivisions and connections creating obstruction to a clear view out. Modules can be used in both laminated and DGU version.

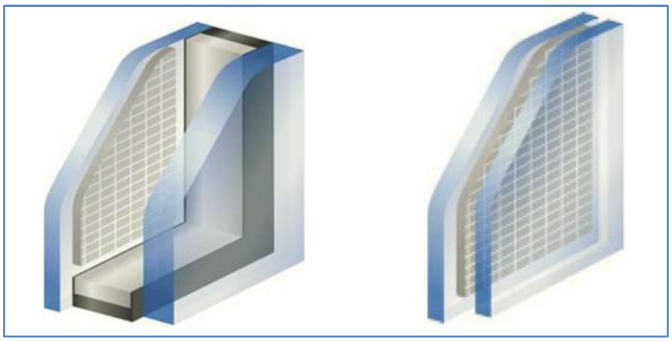


Figure 11: Schott ASi THRU concept (Schott)

Most of the products use amorphous silicon thin film technology, but significant developments in organic PV cells are also recorded.

Figure 12: Schott ASi THRU application

1.1.5.3 Unisolar

Onyx Solar is a Spain based supplier of amorphous silicon thin film modules. Modules are provided in laminated glass and can be installed both as external pane in DGU and as a rainscreen in curtain walls.

Figure 13: Roof application of Unisolar ASi thin film modules (source: Onyx Solar)

Visual aspect of solar cells can be laser dotted or louvered, as shown here.

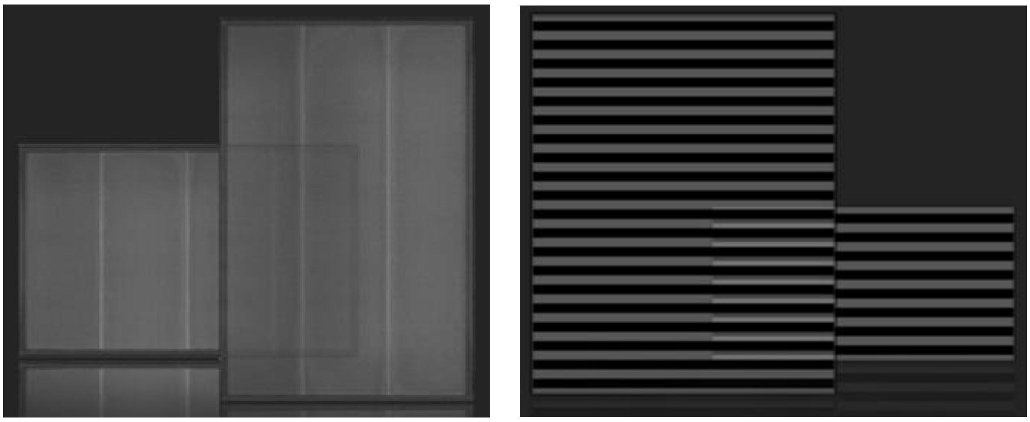


Figure 14: Roof application of Unisolar ASi thin film modules (source: Onyx Solar)

1.2 Installation Options

1.2.1 Transparency

Semi-transparent and translucent PV modules present a wide range of possibilities to combine the production of electricity with natural lighting. In a glass-glass laminate, some light passes through and this is referred to as semitransparency or light-filtering. Given that crystalline cells are opaque, the amount of light passing through is simply determined by the spacing between cells, which can be adjusted from 1 to about 30 mm.

Figure 15: Monocrystalline PV in a semitransparent module (glass on the back). Photo courtesy: M.Art

Thin-film modules have other options for semi-transparency. The cell spacing can be increased for strip-like transparency. Combined with spaced cells, this creates a fine checked pattern that gives an even neutrally coloured average transparency and transmission values of 10–15%. There are some technological developments in which the thin-film is truly translucent but these are not in commercial production.

1.2.2 Colour and texture

Depending on the conservation restrictions, the colour of the PV cells can be identified to match the design requirements.

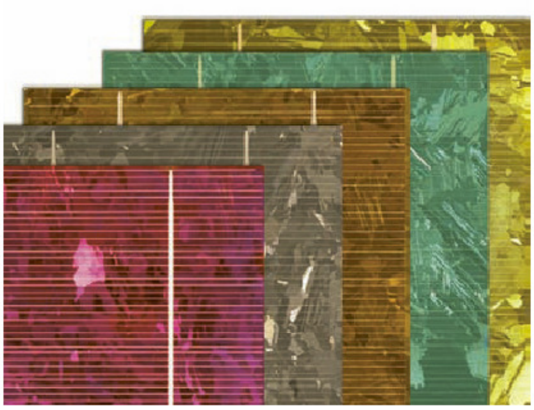


Figure 16: Examples of the coloured effects on polycrystalline silicon cells created by varying the thickness of the anti-reflection coating. Photo courtesy: Sunways AG

1.2.3 Flexible and curved modules

Curved modules with a minimum radius of 0.9 m can be fabricated from crystalline PV cells by embedding the cells between curved sheets or curving finished modules. Thin-film modules are permanently flexible and rollable when deposited onto malleable substrates. Flexible and curved modules are not laminated in hard glass but on a versatile material, e.g. metal and synthetic foils, synthetic resin and glass textile membranes. This is also made possible by new thin layer technologies. The flexible PV modules can be quite light and have been used for arched construction elements, as awnings, flexible roofing with integrated PV cells. When thin-film amorphous silicon is deposited onto a substrate, metal or plastic sheeting can be used which are flexible. Such a system can be rolled onto a standing seam metal roof.

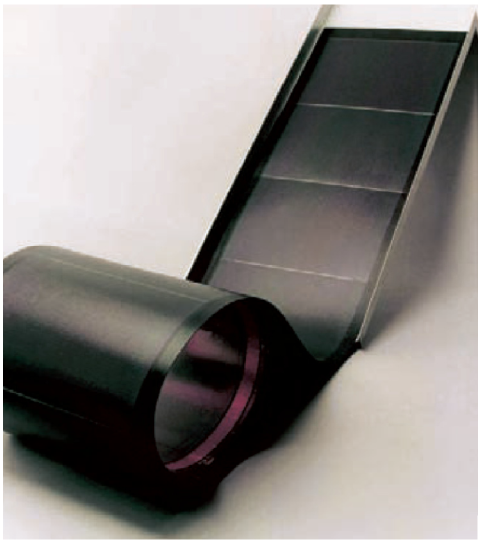


Figure 17: Roll of flexible roofing PV using thin-film amorphous silicon. Photo courtesy: M.Art

Crystalline cells can be laminated with acrylic plastic or Makrolon. The minimal cold-bending radius for cell arrays of 10 × 10 cm is 350 times the thickness of the strongest acrylic plastic sheet.

1.3 Integration in traditional residential

For low-rise traditional housing, the most applicable facade types for BIPV are roof systems and rainscreens.

Low-rise residential are characterised by traditional heavyweight or lightweight timber frame.
PV systems for roofs are well developed. Standard modules are easy to lay on. Proprietary tiles are being introduced enabling simple integration to an increasing range of roof types, as the products from Avancis.

Figure 18: PV integration into a pitched roof (source: Avancis)

Another application of BIPV in residential is made with monocrystalline silicon by Sharp for Upton ZED terrace project.
PV was chosen as the principle electricity generator. PV is referred to as offset since electricity is drawn from the grid when needed, while these renewables export to the grid according to conditions for generation (sun shining). An energy balance between import and export is achieved over a twelve-month period.

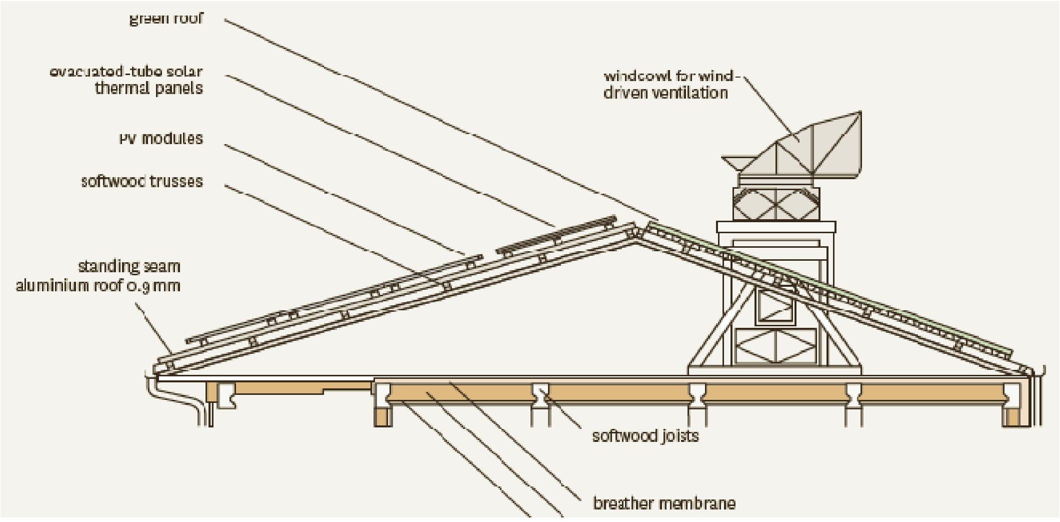


Figure 19: Section through the roof (source: www.zedfactory.com)

To maximise south-facing roof area for PV, the design was slightly modified to move the pitch beyond the terrace centre line. Monocrystalline silicon was selected with 180 WP modules. Twenty modules gives a 3.6k Wp array per dwelling. The modules use a simple frame connection to the standing seam aluminium roof. A 50 mm air space enables ventilation to improve peak temperature, while giving a uniform appearance.

1.4 Case Study – CIS Tower

The Co-operative Insurance Tower is a 28-storey, office building in central Manchester, UK, built in 1962. The building comprises three distinct elements: a podium at the base, office accommodation with glazed aluminium curtain walling and a windowless concrete service tower on the south-west side.

Figure 20: The Co-operative Insurance Tower after and before PV integration (Photo courtesy: Arup)

The architects for the original 1960s design were GS Hay of the CWS and Gordon Tait of Sir John Burnet, Tait and Partners. They decided to clad the concrete service tower with 14 million mosaic tesserae or tiles each 20 × 20 mm. The building is categorised as ***Grade II listed*** ("a building of special architectural or historic interest" within England and Wales). The mosaic tiles were stuck directly onto the concrete structure, but lacking a movement or expansion joint, tension stresses appeared in the grout between the concrete structure and the mosaic cladding. For most of the building's life, numbers of tiles have been regularly separating from the building envelope. An innovative approach to this facade problem was needed and the eventual solution was to clad the failing mosaic with PV modules forming a rainscreen. The resulting PV array could also contribute to reducing the building's reliance on grid electricity through generation of about 180 MWh/y.

In 2003, increasing concerns about the safety issue of falling tiles prompted search for a solution. Three possible options were identified:

1. *Replace with new mosaics* throughout, installing these with stress/expansion joints. The replacement material would be similar to the original so the appearance would have been impacted only by the introduction of the new joints. However removing all the old tiles would be lengthy, noisy and costly.

2. *Remove all the mosaics and paint or render* the bare surface. Although the lowest cost option, this would have met serious problems with the Grade II listing of the exterior, since it would have fundamentally and negatively impacted the appearance of the building.

3. *Overclad to retain the mosaics* while awaiting developments in technology for fixing mosaics to concrete. This approach offered a high degree of certainty as a solution since the existing mosaic finish could remain conserved beneath the cladding. The appearance would be different but there was an opportunity to achieve a high quality and lasting aesthetic result.

If option 3 of overcladding was to be pursued, there was concern over the nature and appearance of the cladding material given the listed status. The option to use PV was going to be challenging but could provide the opportunity to make a difference in using new materials and generating renewable energy with reduced emissions.

The Co-operative Insurance is a company with an ethos for corporate social responsibility. Therefore the concept of generating some of the building’s energy using renewables technology was seen by them as a priority. Concerning the appearance, the planning authority of the City Council accepted that the PV modules could make a very special effect but insisted that the massive monolithic appearance of the service tower needed to be maintained. English Heritage were consulted and they gave listed-building consent for the change.

1.4.1 Choice of PV technology

In the first assessment, thin-film technology appeared to represent an aesthetically suitable cladding material. The modules are a lower cost than crystalline silicon modules. Moreover, standard thin-film modules are available in a variety of sizes. However the planning authority raised concerns about the appearance of the thin film modules on the building. The overall effect would have been too uniform, losing existing identification of the floor-to-floor separation of 3.74 m, a key feature in the original mosaic design.

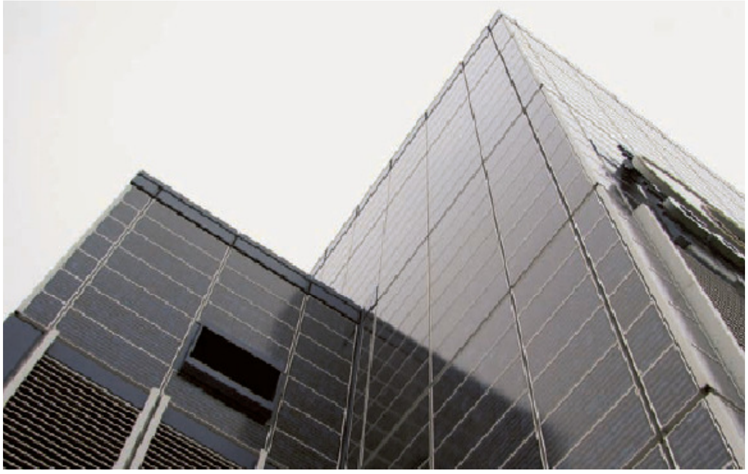


Figure 21: View onto the north west corner showing three types of cladding: cassettes of seven PV modules; narrower PV modules along the corners having identical appearance but electrically inactive; inexpensive coated steel dummy panels used around the vent. Photo: Tom Swailes

Polycrystalline modules have a more desirable appearance. Furthermore the size of standard modules available from Sharp overcame the planners aesthetic concerns. They were 1200 mm wide by 530 mm high with a frame thickness of 35 mm.

The rainscreen used for the cladding is a pressure-equalised type. The wall is concrete so installation of the rainscreen was mostly concerned with mounting the PV modules. Before installing the photovoltaic modules, a metal mesh was fixed over the mosaic for retention.

1.4.2 Electrical

Each cassette of seven modules was connected in series, and three cassettes were joined to make a string operating at about 360 V DC. Each string was connected back to a DC insolator by a pair of double-insulated, single-core cables. These were inserted in a cable tray, attached to the cladding support structure and mounted within the 25 mm zone defined by the angles retaining the mesh.

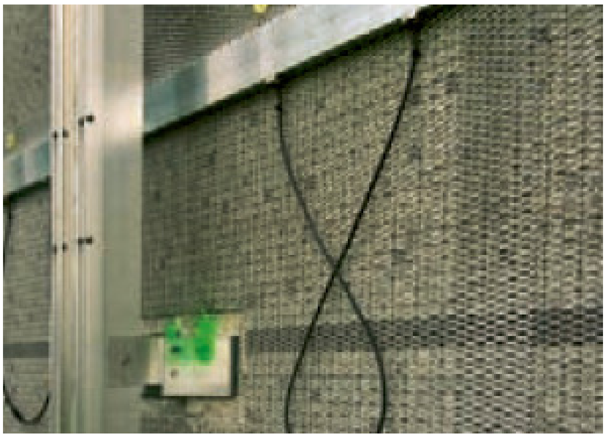


Figure 22: PV integration: retaining mesh and cable tray for wiring (Photo courtesy: Arup)

The DC insolators are sized to enable the DC supply into the inverter to be safely disconnected, even under full-load conditions. Inverters take the DC power generation from the series-connected strings of PV modules and convert it to useful AC power for use within the building. The output from each inverter was routed into an AC distributor sub-panel and then above the main lift lobbies false ceiling and into the pilot busbar riser cupboard at each floor level. There are six main points of PV system AC output connection into the building's existing AC distributor system.

2 Solar-cooling

The purpose of this technical note is to:

- Summarise the heat requirements for various thermally-driven cooling technologies.
- Summarise the heat generation potential of various solar collectors
- Identify different centralised and distributed configurations for heat collection and cooling generation.

Description

Arup is considering the wide-scale use of thermally-driven cooling, in particular absorption chillers, as a means of achieving a low – carbon city. The attraction of thermally-powered cooling systems is that they can potentially make use of waste heat from electricity generation or use solar energy from thermal collectors. It is expected that there will be an emissions saving by using thermal energy from waste and solar sources to drive thermal chillers, instead of electrical energy from a gas turbine to run an electric chiller.

There are a range of possible configurations because the solar collectors and cooling equipment can either be distributed or centrally located. The waste heat from electricity generation is only available at central locations. The different configurations have different implications for distribution and different possible advantages and disadvantages; centrally collecting the waste heat and solar energy and locating the cooling technologies in the buildings is often the best option to follow. All basic configuration have been considered here to provide a complete, albeit high-level, review.

Note that heat rejection equipment could also be located centrally, with a citywide condenser water loop, or distributed (i.e. in each building). This has not been considered in this technical note but could have implications with respect to microclimate and the heat-island effect. [1]

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[1] Dhakal, S. and Hanaki, K. (2002) Improvement of urban thermal environment by managing heat discharge sources and surface modification in Tokyo, *Energyand Buildings*, Volume 34, Issue 1, Pages 13-23

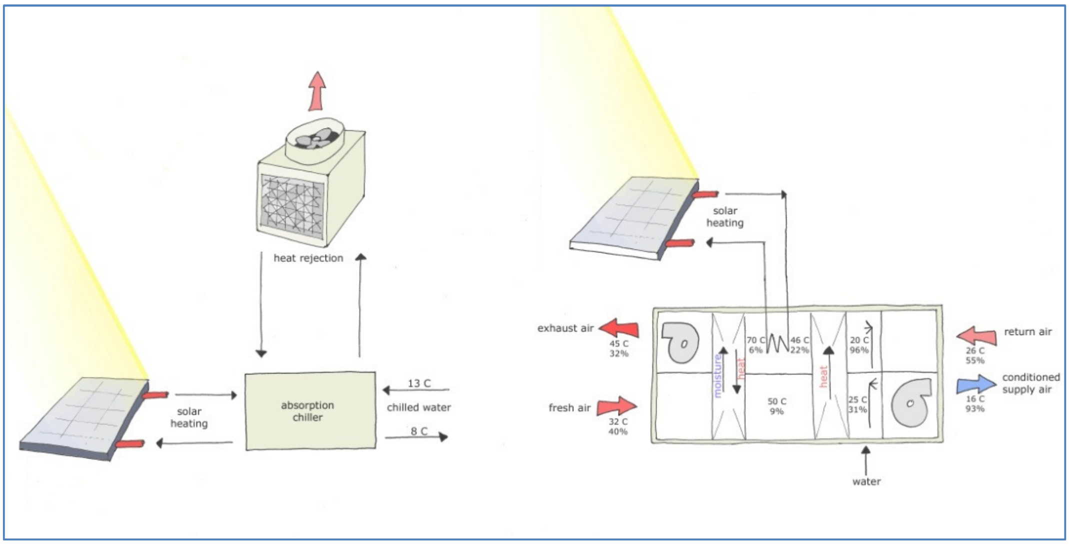

Figure 23: Solar cooling (Arup)

Key Information

Arup has conducted a high level review of thermally-driven cooling technologies:

- absorption chiller: a liquid or solid sorbent absorbs refrigerant molecules into its inside, absorbs heat and changes physically and/or chemically in the process;
- adsorption chiller: a solid sorbent that attracts refrigerant molecules onto its surface by physical force and does not change its form in the process;
- chemical adsorption chiller: a solid sorbent that attracts refrigerant molecules onto its surface by chemical force and does not change its form in the process;
- desiccant cooling: a sorbent (i.e. a desiccant) absorbs moisture from humid air (figure 24[2])

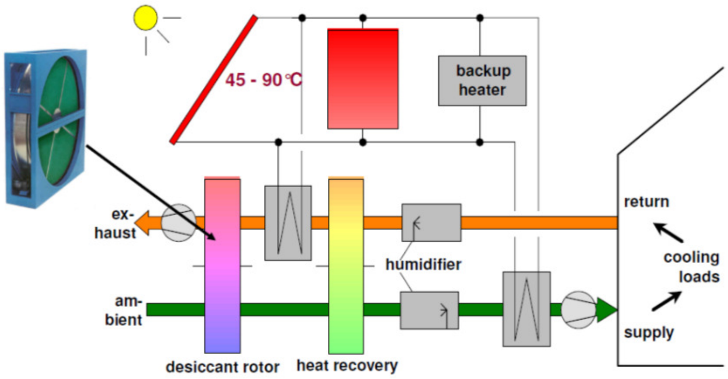

Figure 24: Dessicant cooling

- thermomechanical vapour compression: a heat engine (e.g.rankine, stirling, steamjet) is used to drive a vapour compression cycle;

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[2] I sistemi di condizionamento ad energia solare Tecnologie, realizzazioni e mercato. Solar cooling: aspetti tecnologici- Mario Motta-Politecnico di Milano

- PV powering an electric chiller: PV cells are used to generate electricity to power a standard vapour compression chiller.

In general, we have noticed that absorption chillers are the most commercially mature of the technologies and have the highest Coefficients of Performance (COP). However, to achieve the higher COPs requires a heat source above ≈ 120°C. The review also indicates that there are a number of technologies undergoing research and development and which could become commercially

available while MAA is being built. Note that the COPs listed relate to either the refrigeration process only, or the conversion from solar energy to cooling energy. They do not include electrical energy required for pumping or fans. For a true comparison, different cooling options should be evaluated based on a more holistic basis, such as primary energy[3] electrical COP (kW cooling/kW of electrical input).

Arup have also conducted a high level review of various solar collector technologies.

- Flat plate: flat plate collector consists of a metallic plate under a glass cover. Solar radiation is absorbed by the plate and the energy transferred to fluid-filled pipes attached to the plate. The glass cover helps to reduce heat losses.
- Evacuated-tube : an evacuated tube collector consists of multiple tubes connected to a header. Inside the tubes is a metallic plate and pipe. The tubes are at a pressure of a few Pascals only to reduce heat losses. Evacuated tubes may be mounted in front of reflectors.
- Stationary compound parabolic concentrator (CPC): operates similar to a flat plate collector except that strips of metallic plate are mounted above parabolic troughs. A glass cover is used to reduce heat losses.
- Solar air collectors: similar to flat plate collectors except that the heat transfer fluid is air.
- Parabolic trough: a sun-tracking parabolic trough concentrates solar radiation onto a receiver pipe or heat collection element.

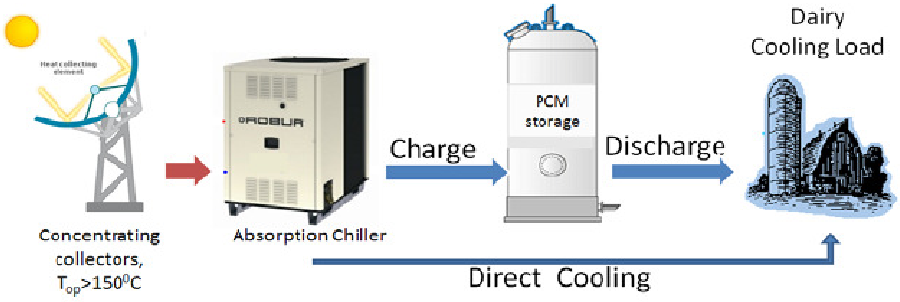

Figure 25: Simplified scheme of solar cooling system

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[3] Henning (2004) Solar-assisted air-conditioning in buildings, Springer, New York.

- Power tower (central tower surrounded by focusing mirrors): a central tower is surrounded by suntracking mirrors (heliostats) which focus solar radiation on a receiver at the top of the tower.

The studies carried out about these technologies, show that temperatures from about 50°C up to 500°C can be achieved. This covers the range of temperatures required by the thermally-driven cooling technologies. Some technologies, such as flat plate and evacuated tube collectors, could be used in a centralised or distributed way. Others, such as solar air heaters, could be used in buildings in conjunction with desiccant cooling. Others again, such as parabolic troughs or power towers could be used in a centralised way, possibly with triple effect absorption cooling.

Other studies could be carry out considering the basic possible combinations of solar thermal collectors and cooling equipment:

Configuration	**Electricity generation location**	**Solar thermal collector location**	**Cooling equipment location**	**Distribution heat transfer fluid**
District cooling	Centralised	Centralised	Centralised	Chilled water
District thermal system	Centralised	Centralised	Distributed	Hot water / steam
Mixed system	Centralised	Distributed	Centralised	Chilled water
District thermal system **with building based solar boosting**	Centralised	Distributed	Distributed	Hot water / steam

Guidance

Based on the information in this technical note, we suggest the following courses of action:

- Agree on an appropriate metric for comparing different cooling options. Electrical COP seems promising, although would not necessarily distinguish between electricity sources of different emissions intensities (e.g. PV compare to gas turbine).
- Further consider the possible advantages and disadvantages, both to building design and city design, of the configurations presented here. In reality there could be a combination of configurations depending upon the governance arrangements (e.g. whether buildings are required to connect to a district system or whether it is optional)
- Consider centralised and distributed heat rejection options and the possible micro-climate and heat island effects.

3 Credits

Section 1

Simon Roberts & Nicolò Guariento, Building Integrated Photovoltaics: A Handbook (Birkhauser Verlag AG) 184 pages, 2009, ISBN 3764399481

ANNEX 3

Internal Insulation and Moisture

P05 - ARUP

European Commission - FP7

3ENCULT

Internal insulation and moisture transport

Report Ref

Issue | March 2011

Job number 077315-94

Arup Italia srl
Corso Italia 13
20122 Milano
Italia
www.arup.com

Indice

1 Internal insulation

1.1 Thermal upgrading

Three general requirements often prove difficult or impossible to satisfy in historic buildings:

- **Insulating the structure uniformly, avoiding thermal bridging**. Problems often arise at the junctions between different elements and construction details. Ensuring continuity is often difficult;
- **Providing a well-controlled heating system**, with heat emitters in rooms where heat will not be gained from heated spaces elsewhere. This is to help reduce moisture levels and avoid condensation. However, in many historic buildings there are unheated rooms, void structural gaps and other spaces in which condensation risks could increase if other parts of the building were upgraded and/or air infiltration rates were reduced too far.
- **Preventing the distribution of humid air throughout the building,** particularly to unheated spaces, by passive or mechanical ventilation close to the source historic buildings – or at least in parts of them – it may be impossible to install such systems without damaging their character.

- ➢ A comprehensive overview of insulation options for several construction typologies can be found in *“Thermal insulation: avoiding risks”, Stirling [BRE, 2002]*.

1.2 Insulation strategy

Adding insulation in existing building has the basic function to reduce heat losses due to thermal transmittance and air leakage.

As reference, the graph below reports the heat losses distribution in a traditional cottage. Walls and roof usually account for more than 50% of heat losses

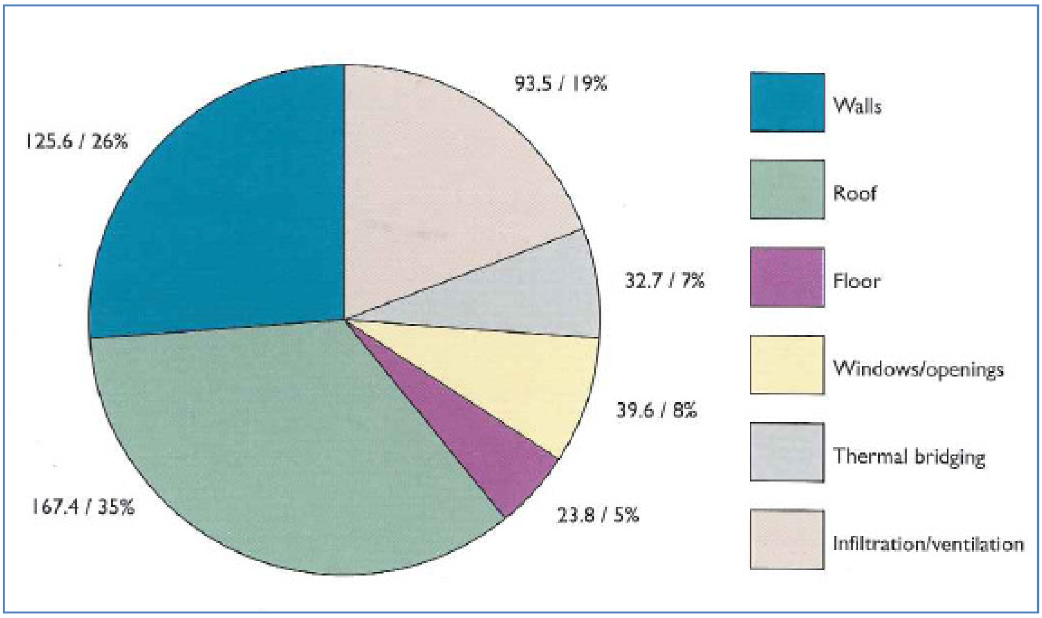

Figure 1 Heat losses distribution in a traditional cottage[1]

Insulation would involve several constructions:

- Pipeworks, boilers, tanks, etc.
- Roofs, pitched roofs, flat roofs, thatched roofs,
- Walls insulation
- Floor insulation

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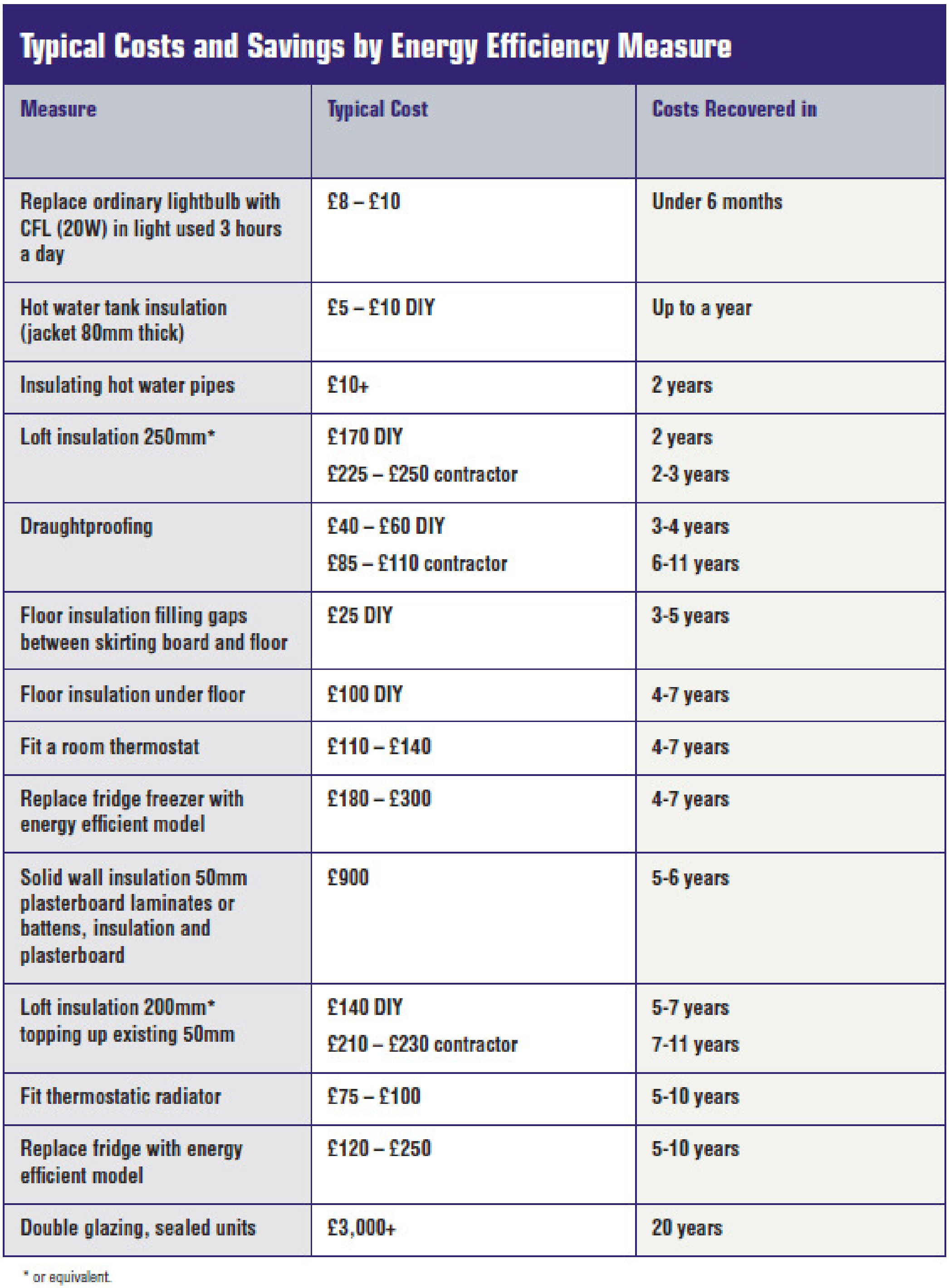
[1] The green guide for historic buildings: how to improve the environmental performance of listed and historic building, Prince's Regeneration Trust, March 2010.



Typical Costs and Savings by Energy Efficiency Measure

Measure	Typical Cost	Costs Recovered in
Replace ordinary lightbulb with CFL (20W) in light used 3 hours a day	£8 – £10	Under 6 months
Hot water tank insulation (jacket 80mm thick)	£5 – £10 DIY	Up to a year
Insulating hot water pipes	£10+	2 years
Loft insulation 250mm*	£170 DIY £225 – £250 contractor	2 years 2-3 years
Draughtproofing	£40 – £60 DIY £85 – £110 contractor	3-4 years 6-11 years
Floor insulation filling gaps between skirting board and floor	£25 DIY	3-5 years
Floor insulation under floor	£100 DIY	4-7 years
Fit a room thermostat	£110 – £140	4-7 years
Replace fridge freezer with energy efficient model	£180 – £300	4-7 years
Solid wall insulation 50mm plasterboard laminates or battens, insulation and plasterboard	£900	5-6 years
Loft insulation 200mm* topping up existing 50mm	£140 DIY £210 – £230 contractor	5-7 years 7-11 years
Fit thermostatic radiator	£75 – £100	5-10 years
Replace fridge with energy efficient model	£120 – £250	5-10 years
Double glazing, sealed units	£3,000+	20 years

* or equivalent.

Figure 2 Costs and savings by Energy Efficiency Measures[2]

In the following sections is a brief description of technical solutions.

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[2] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

1.2.1 Pipeworks insulation

Insulating pipeworks, ducts, boilers, hot/cold water tanks would reduce loss of heat generated for conditioning the building and provide hot water. Picture below shows a tank insulation, which should be applied all around but not between the tank and the room.

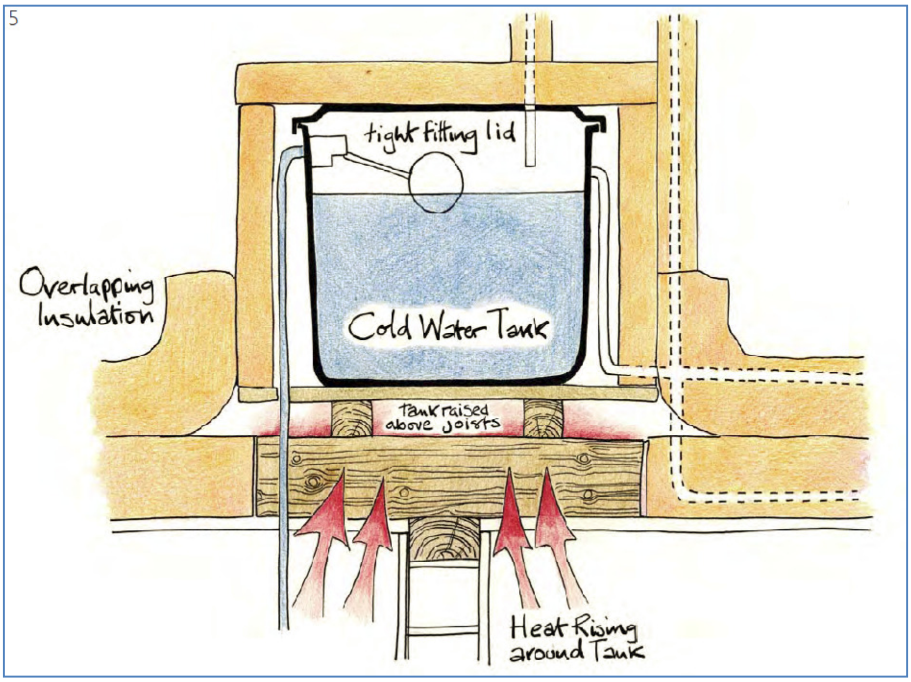

Figure 3 Insulation of a water tank.[3]

This solution usually has not any visual impact and then should be systematically pursued when intervention on existing buildings are planned.

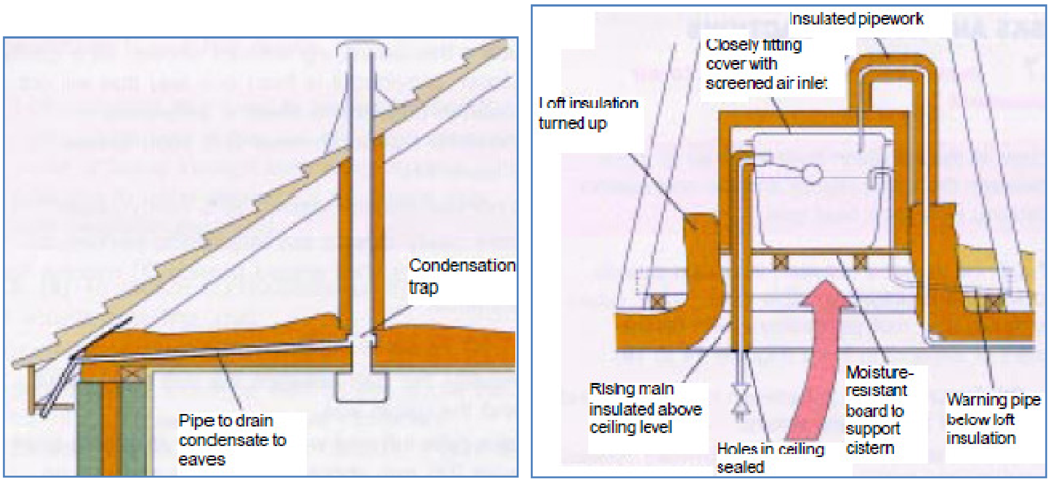

Figure 4 Insulation of an extract duct (sx) and of pipes and cistern (dx).[4]

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[3] Energy Conservation in traditional buildings, English Heritage, June 2007.
[4] Thermal Insulation avoiding risks, BRE (C. Stirling), 2002.

1.2.2 Roof insulation

Next step after insulating pipeworks is roofs' insulation, which is an extremely cost-effective solution to reduce energy losses and CO2 emissions.

Insulation should be installed throughout rather than partially. In fact, partial insulation would be the worst case scenario, causing cold bridging and condensation forming, thus damaging and deteriorating the building components: timber rot due to condensation and moisture forming on the ceiling below the loft are the most frequent issues.

1.2.2.1 Pitched roofs

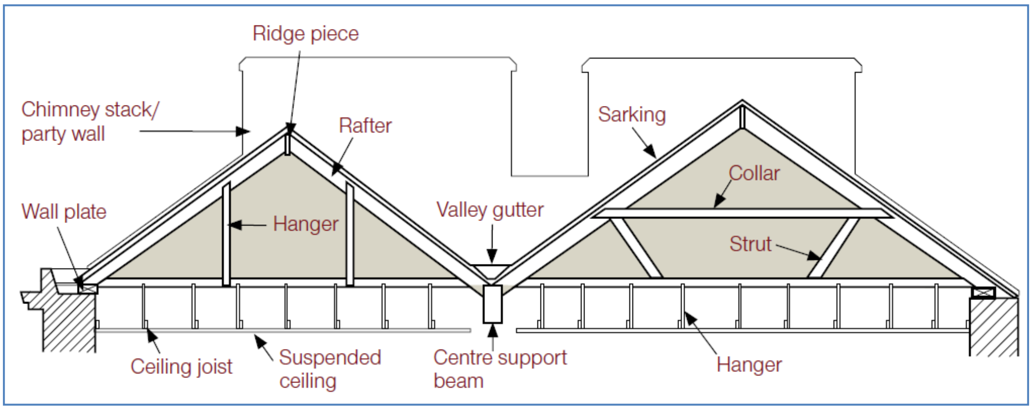

Figure 5 Typical double pitched roof construction.[5]

Insulation should be installed directly above the top floor ceiling. If ceiling joists are present, insulation should be placed in between.

In attics used for accommodation, insulation can only be installed on the underside of the rafters. Insulation in between rafters is risky and should be done very carefully, as it could cause mould developing between insulation layer and vapour breathing barrier. When applying insulation below rafters, micro-ventilation should be guaranteed to avoid condensation forming below roof slates.

Loft insulation is the most basic and usually the cheapest and easiest insulation measure, saving up to 20% of heating energy. Thickness should be around 250 mm to obtain a reduction from 2.3 to 0,15 W/mK, which would be the expected target set by Public Bodies in UK.

In pitched roofs it is fundamental to maintain the ventilation around the eaves, to avoid moisture building up below slates. Therefore, any additional insulation should not compromise the ventilation.

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[5] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

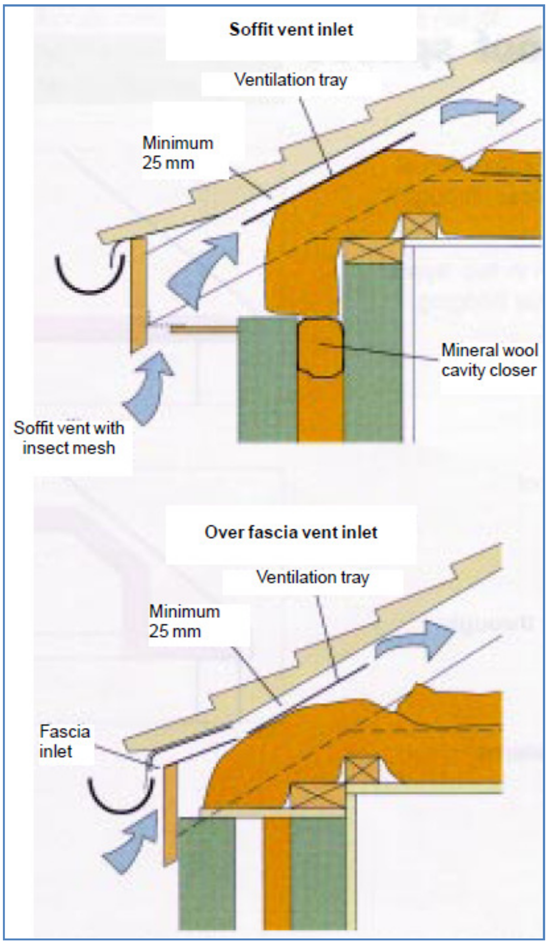

Figure 6 Ventilation options in the roof space[6]

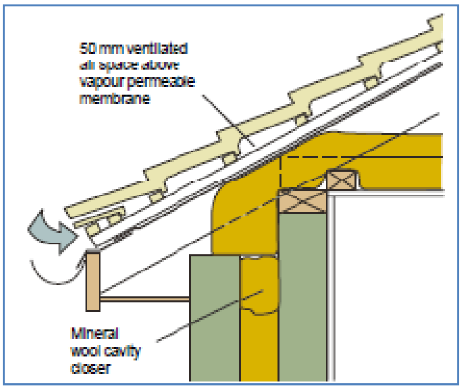

Figure 7 Cold pitched roof incorporating a vapour membrane

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[6] Thermal Insulation avoiding risks, BRE (C. Stirling), 2002.

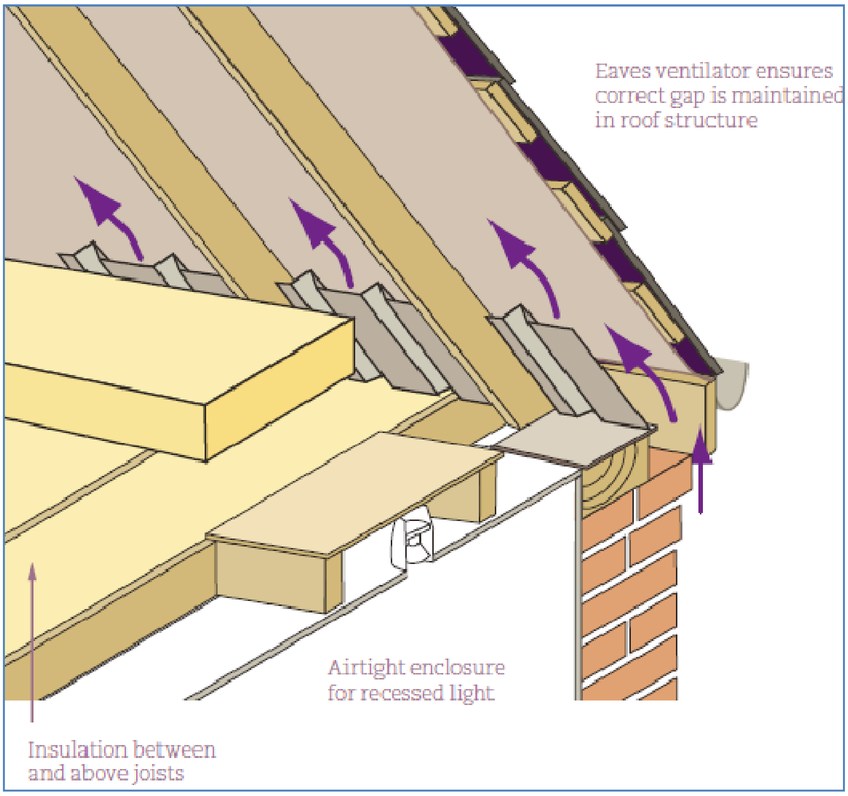

Figure 8 Loft insulation.[7]

Most common materials for loft insulation are soft insulating quilt, which can be made of mineral fibre and natural materials (cellulose fibre, sheeps' wool, hemp, cotton). Blown or loose fill insulation is also used, as mineral fibres and cellulose fibres. Natural materials are usually more appropriate in listed buildings, due to their tendency to breathe; besides they are more sustainable, having a lower embodied energy. Non permeable materials (like foil-backed insulation and membranes) must be avoided.

In the next section, some possible insulation materials are listed.

1.2.2.2 Flat roofs

Warm deck

The insulation is placed above the roof deck, but below the weatherproof membrane. Ventilation is not required since the insulation is bedded on a continuous vapour control layer. This method is used above timber, concrete and metal structural decks.

This insulation method is appropriate when the weatherproof membrane of a concrete or timber warm deck flat roof has failed and needs to be renewed or where the membrane is in good condition, but the insulation needs to be upgraded. For timber flat roofs, the method may also be used to replace a cold deck construction where only the structural joists are in a satisfactory condition.

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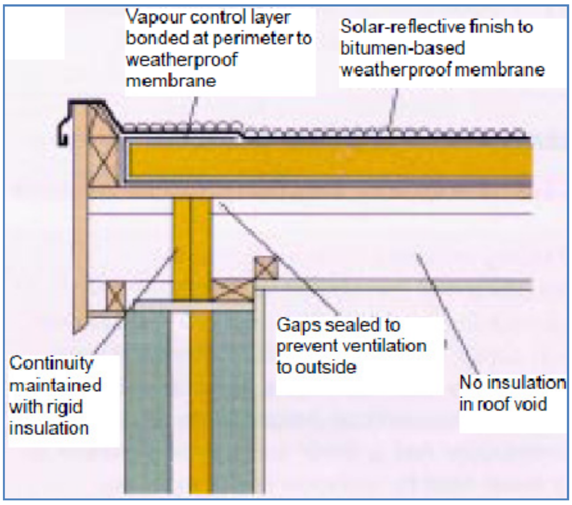
[7] Fit for the future. The green homes retrofit manual – technical manual, Housing Corporation, June 2008.

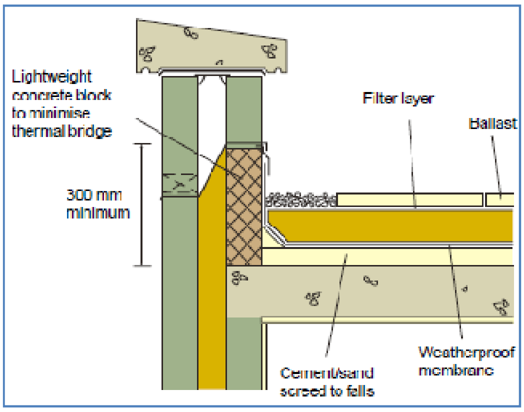


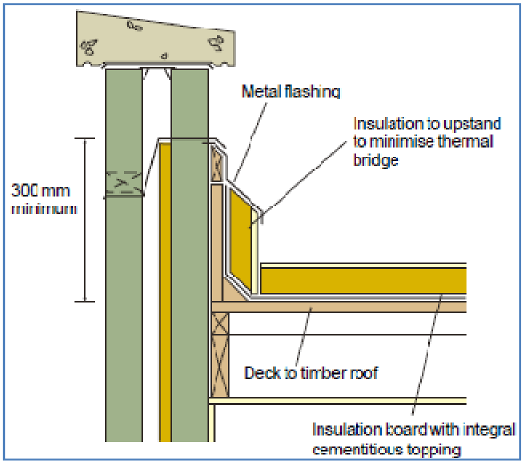
Technical Risks:

- Fatigue of weatherproof membrane;
- Insulation damaged by heat during construction;
- Fire spread from a melting or burning weatherproof membrane and combustible insulation;
- Condensation within the construction;

Inverted Warm deck

The insulation is placed above the weatherproof membrane. It is protected from UV degradation and held down against wind uplift by edge restraint. The method can be used above concrete, metal and timber structural decks. Concrete decks are capable of supporting a ballast layer of paving slabs. With lightweight decks, that cannot carry heavy ballast, use a permeable sheet topping to restrain tongued and grooved insulation boards to create a fully interlocking layer.





Technical Risks:

- Increased heat loss due to rain cooling
- Condensation through chilling of lightweight metal decking
- Degradation of the insulation

- Abrasion of the weatherproof membrane

Cold deck

The insulation is placed at ceiling level with a void ventilated to the outside between the insulation and the deck. It should be considered *only for timber construction*. With increased levels of insulation it may prove impractical to achieve the desired thermal performance and the required ventilation without increasing the depth of the joists by additional battening. The preferred option is to provide a warm deck flat roof. The cold deck roof should not be an option in the temperate, humid climate, where sufficient ventilation may not be achieved. It is usually not possible to upgrade the thermal insulation value of an existing cold deck roof. The preferred option is to convert it to a warm deck flat roof.

Technical Risks:

- Condensation within the roof
- Condensation at thermal bridges

1.2.3 Floor insulation

In typical houses and buildings, ground levels floors account for around 15% of total heat loss. Additional insulation can be installed either on "ground built" surfaces or suspended timber floors.

Floor insulation can be very effective and the target U-value should be around 0.6 W/m²K for basement floors form the usual 3.5 W/m²K before of intervention.

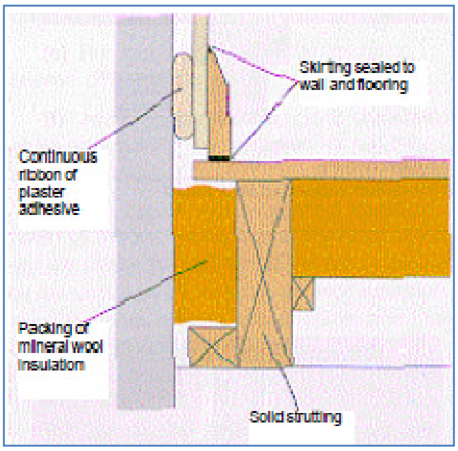


Figure 9 Continuity of floor insulation.[8]

1.2.3.1 Installation from below

Installation of soft insulation from below of suspended timber floors, where joists are exposed, would be easier. Insulation should be fitted between floor joists. A net will hold them in correct position.

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[8] Thermal Insulation avoiding risks, BRE (C. Stirling), 2002.

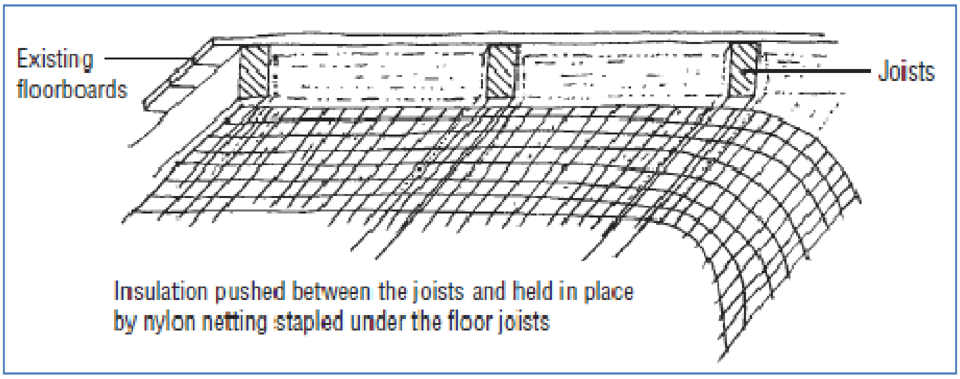

Figure 10 Typical insulation between joists applied from below.[9]

1.2.3.2 Installation from above

Floorboards must be lifted to access installation space and then re-laid. Particular care should be taken with old wide hardwood boards, with tongue and groove edges. These boards should be retained as much as possible, as they provide better insulation than butted floorboards. In suspended timber floors, thinner insulation could be used, as a layer is usually already present below floorboards. Either battens (fitted to the side of joists) or plastic net must be installed before of laying the insulation.

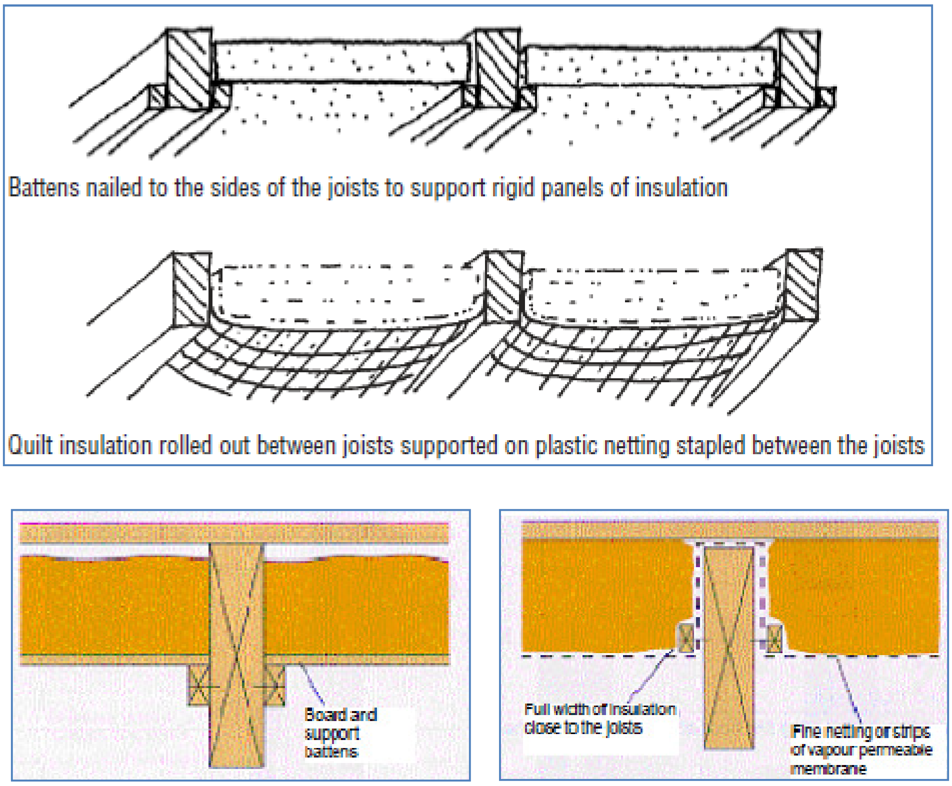

Figure 11 Insulation between joists installed from above. Timber supported (left) or plastic net support with side battens (right).[10]

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[9]

[10] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

2 Moisture Transport

2.1 Internal insulation and moisture

When adding insulation to a modern structure, it is routine to check the construction for interstitial condensation. If it is predicted, a further calculation should be carried out to see how serious the build up of moisture at the condensation plane is likely to be, both in its own right and by putting any materials, like timber, present at risk of decay.

2.2 Fabric changes

Changes to the fabric of a building in order to reduce heat loss can alter its moisture transfer mechanisms, including the ability of the fabric to 'breathe'. Three important aspects of moisture transfer contribute to maintaining the balance of moisture content found in many historic buildings:

- **permeability**: the capacity to allow water vapour to pass through;
- **capillarity:** the ability to mop up or wick away water as liquid;
- **hygroscopicity**: the tendency actively to draw moisture from air and store it.

If too much moisture accumulation is predicted, the normal solution in a modern building is to introduce a high-resistance vapour-control layer on the warm side of the insulation to prevent the water vapour diffusing out into the structure.

Even if a calculation shows that condensation by diffusion will not occur, caution is still needed. If there are air gaps or cracks through the structure (as there often are around the edges and at joints), moist indoor air can ex-filtrate quickly and directly to the cold structure, by-passing the vapour-control layer and creating a risk of localised interstitial condensation. Great care must therefore be taken to seal any insulation on the warm side against bulk air movement.

However, even if the insulation and the vapour control layer are installed successfully, there can still be problems in a traditionally constructed building. The vapour-control layer intended to prevent moist indoor air from diffusing into a modern wall also blocks the low-vapour-resistance 'breathable' path for structural moisture to escape internally. This can lead to increased dampness and even decay.

When selecting insulation materials for older buildings, a further degree of safety can be provided by using materials which are **hygroscopic, e.g. natural insulation materials such as sheep's wool and cellulose fibre**. These can absorb some excess moisture without leading to condensation or decay, and release it when conditions are more favourable.

2.3 Vapour barriers

For older structures, it is therefore important that new insulation does not disturb the moisture balance significantly. One way to achieve this is to control interstitial condensation not by using a high-resistance vapour-control layer (e.g. a

polyethylene membrane), but by adding a layer of much lower vapour resistance - sufficient to prevent the interstitial condensation, but not enough to destroy the ability of the fabric to 'breathe'.
A simple rule of thumb for initial consideration is that the **vapour resistance** inside the likely plane of condensation (which is normally where the internal insulation meets the external fabric) **should be at least five times 'the resistance between this point and the outside of the building**.

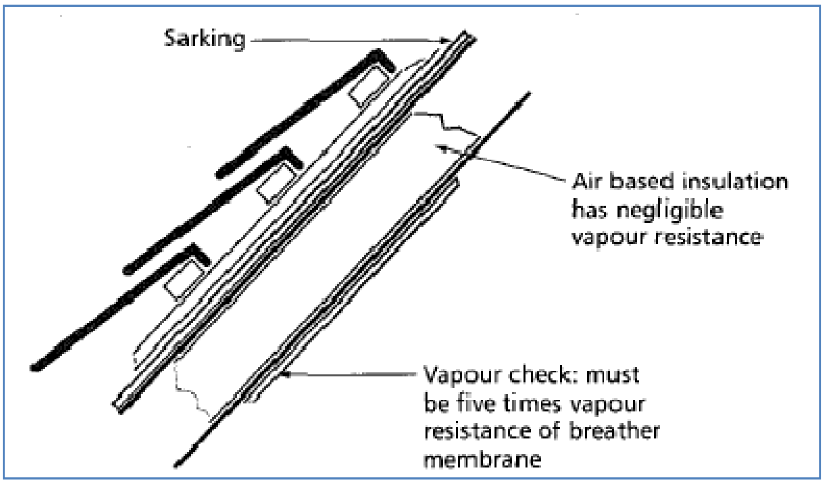

Figure 12 Typical section showing points for vapour resistance checking.[11]

2.4 Breathing walls and connections

Traditional buildings, including most historic buildings, tend to be a solid-wall construction, built primarily with porous fabric that absorbs moisture, but also allows it to evaporate readily. This would be the ability of the building fabric to 'breathe'. So, "breathing wall" does not mean that air exchanges occur through walls, because building materials basically do not "breathe". Also the idea of having hygroscopic materials that themselves alone are able to regulate moisture air content is not founded, as air humidity can be regulated to a limited extent by interior surfaces, which may help reducing peak levels. Besides, insulation materials often do not participate to these processes as they are covered by other layers.

An old building uses evaporation and ventilation to reduce the moisture in the walls to an acceptable level, i.e. one that does not cause decay, mould growth, or damage to decorations. Evaporation and moisture buffering effect are useful just to reduce peak levels of moisture content in old construction, but a dry environment can only be achieved by a conscious design and exploitation of ventilation.

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[11] Guide to building services for historic buildings. Sustainable services for traditional buildings, CIBSE, November 2002.

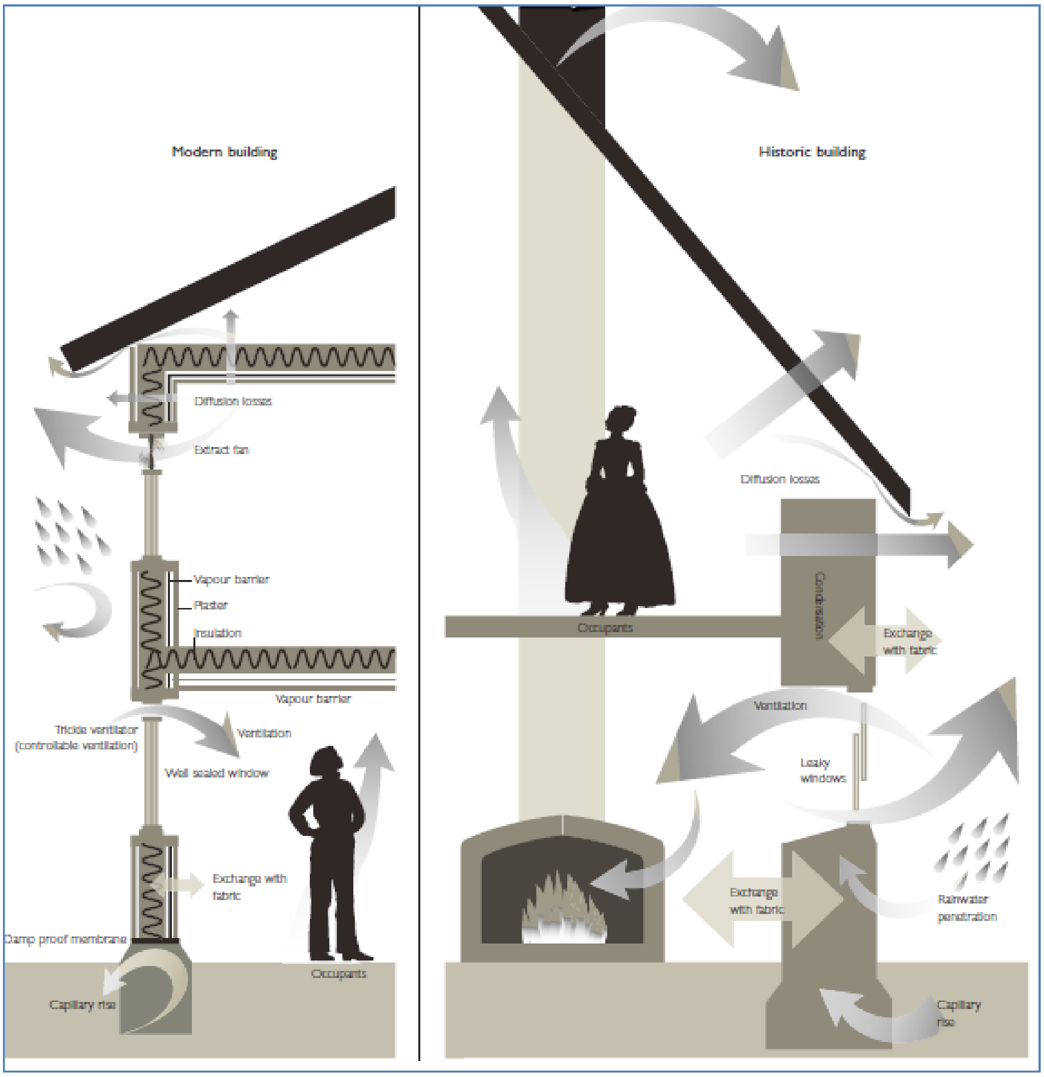

Figure 13 Comparison of air movements and moisture transfer in new and old buildings.[12]

In contrast, many modern insulation techniques include impervious vapour control layers, designed to stop moisture from indoors diffusing out through the insulation and leading to interstitial condensation. However, if these same impervious layers are used in a traditional building, they can trap the moisture already in the wall and stop it evaporating, making the wall damper and more prone to decay.

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[12] Building Regulations and Historic buildings, English Heritage, March 2004.

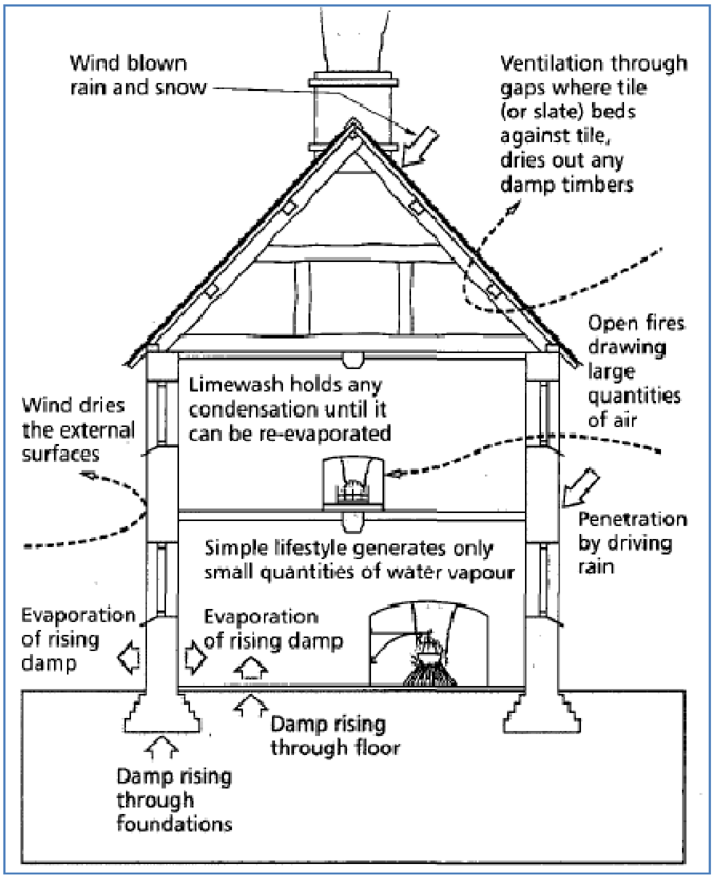

Figure 14 Typical moisture movement in an old building.[13]

In older buildings there is a dynamic equilibrium between absorption and evaporation. To keep the fabric reasonably dry and the internal environment healthy, extra indoor ventilation is required to remove the moisture that evaporates. Further moisture is driven off when the building is heated, so any extra heating may also require more ventilation.

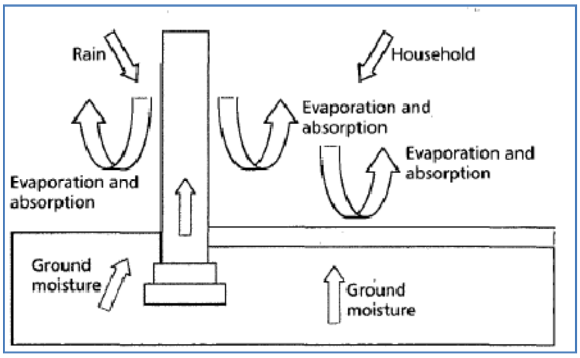

Figure 15 Moisture control in old buildings at wall to ground connection.[14]

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[13]

[14] Guide to building services for historic buildings. Sustainable services for traditional buildings, CIBSE, November 2002.

2.5 Hygroscopic insulation materials

Most of insulating materials are not hygroscopic, so they cannot absorb moisture and they are given a water repellent treatment; they also do not support any capillary action. Anyway, some hygroscopic and capillary active materials are present in the market.

Cellulose fibre

As listed above, one of the most interesting materials and innovative materials to be used for internal insulation is cellulose fibre. It comes from scrap paper + 8-20% of powdered boric salts, which improve reaction to fire. Boards are produced mixing paper with fibres and binders, pressing them together in steam. Density is 30-80 kg/m³ for a thermal conductivity range of 0.040-0.045 W/mK.

Figure 16 Scrap recyclable paper: raw material for cellulose fibre production.

Cellulose insulating materials are open to diffusion and can compensate humidity. Typical application for flakes is filling voids between joists of roofs and timber stud walls. Application is made with a spray on and compacting process; then the cellulose has to dry-up and harden. The layer can then be plastered. The selection of plaster must consider the properties of cellulose fibres materials. In fact, it is a capillary active, which allows for water vapour transportation in its fibres; therefore the plaster layer should improve air tightness, provide water tightness, but any obstacle to vapour transport would be reduce the effectiveness and deterioration of insulation.

Figure 17 Cellulose flakes spray application (left) and roof sprayed insulation (right).

However, sprayed-on solutions should be carefully used as they prevent proper inspection and compromise the re-use and recycling of adjacent materials.

Calcium Silicate Foam

A comprehensive list of performance for Calcium Silicate is contained in the table provided by Remmers.
Calcium Silicate Foam Boards are produced from calcium and silicon oxide, with few parts of cellulose (around 6%), which improves the flexibility of boards and the stability of the edges. Boards are produced putting the mixture in autoclave, under action of pressure and steam. Finally, an open cell, rigid foam is obtained, which is processed to achieve hydrophobic properties. Density is high; typical range is 200 to 300 kg/m³.
Insulation properties are not extreme (0.040-0.045 W/mK), but boards have a good mechanical resistance in compression and dimensional stability. Most important feature is their capillary action, which allow moisture absorptance, storage and release, which makes it one of the most viable solutions for internal insulation. In contrast with usual internal insulation materials application, a vapour barrier should not be installed.
Weak point about the use of this material is high energy demand for its production, even if raw materials are available in large quantities.

Cork Boards

Historically, cork has been used since the 2nd century. Cork boards are manufactured from cork oak and sometime from recycled cork. Cork is grounded to form a granulate and expanded in autoclave; granulated cork (3-10 mm) is then pressed in blocks. Granulates are bound with resin released from the cork itself during the pressing process. Products could also be impregnated by adding some bitumen.

Figure 18 Use of cork boards for roof insulation

Cork has good sound and thermal insulation properties (100-200 kg/m³; 0,045-0,060 W/mK); it is impervious with respect to air and water, but allows for diffusion. In fact it does not age or rot and does not provide nutrients for insects.

A critical point from the ecological point of view is the relatively limited stock of cork oak tree and sometimes the very long transport distance, as it comes mainly from Mediterranean Europe. Cork grows slowly and the risk of "overharvesting" is high. Except for the impregnated one which can only be reprocessed, cork is recyclable, used for loosening soils or composted.

Sheep's wool

Insulating material comes from pure sheep wool, which is sometime obtained from recycled wool. Some additives (sodium salt, urea) protect the wool against moths and insects. Thin batts (less than 100 mm) are often reinforced with polyester fibres and natural latex milk.
Sheep's wool has good insulating properties (0,040-0,045 W/mK), is hygroscopic and rot-resistant. It can absorb up to 30% of its weight in moisture and release it quickly. It is also used as impact sound insulation infill between structural elements.

Figure 19 Internal insulation with sheep's wool boards in between studs.

Sheep's wool is a natural product, but it is affected by a quite energy consumption of cleaning agents and flame retardant; besides, in the event of fire, the keratin in the wool would cause toxic substances to be released.

Wood Fibres

The raw material for wood-fibre insulating materials comes from long-fibre softwood and sometimes also hardwood (waste products). Boards are treated with boric acid to provide fire resistance and maybe and also with bitumen for hydrophobic treatment (not to be used as internal insulation!). Wood is broken down to in chips and then turned into a pulp in autoclave before pulverisation. Fibres are then mixed with the binder and pressed to form boards. Binder is either latex or wax emulsion.
Wood fibres boards have good thermal and sound insulation properties (0,040-0,090 W/mK). They are open to diffusion. Light wood-fibre products have better thermal insulation properties, can absorb moisture and release it quickly, but tend to swell. They also have good resistance to mould and insects.

3 Open issues and guidelines for the project

- Investigate possible weak points of internal insulating materials in respect with conservation issues.
- Assessment of capillary active products behaviour and properties in different climate conditions.
- Check suitability of other natural low embodied carbon materials for internal insulation and moisture transport.
- Development of improved and “historical-friendly” application techniques, mainly in joints and connections.
- Installation and sealing techniques.

ANNEX 4

Windows Integrated shading design

P05 - ARUP

European Commission

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Windows and integrated shading devices

077315-94

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Arup Italia srl
Corso Italia 13
20122 Milano
Italia
www.arup.com

Job number 077315-94

ARUP

Indice

Appendici

Appendice A

1 General

The refurbishment of existing building stock is due to be a key growth area in the decade commencing 2010. Many envelopes are performing poorly thermally or are overheating due to increased internal heat gains. The physical fabric of the cladding is degrading structurally. Buildings are looking tired and in need of a refreshed image. Besides, refurbishment of an existing structure has potential cost and sustainability advantages over complete demolition and rebuild. Many new materials are now available.

- **Building Physics Informed Design**

  The first question in a building refurbishment is to understand how the existing building performs; what are its strengths and weaknesses and where it has fallen short previously. The skills of the Building Physicist can pinpoint the reason for high energy bills, uncomfortable conditions or condensation and advice on corrective measures and strategies for improving the façade's performance. New designs for upgraded facades can then be modelled in a similar way, to quantify improvements and assess benefits against build costs. This approach informs decision making.

- **Sustainability**

  Sustainability must be integral to the process, considering the longevity of the materials used and the energy efficiency of the façade from the initial stages onwards rather than, being an after thought.

- **Materials**

  Materials specialists with conservation expertise should be involved in the process: metallurgists, glass specialists, geologists, ceramics, plastics and concrete experts.

2 Windows refurbishment

Windows typically account for only 10-20% of heat losses of a building. Anyway, it usually is one first building elements to be improved in a refurbishment operation. The appearance is a significant factor in shaping the overall character of the building and this can drive the choice of the improvement options available for historic buildings.

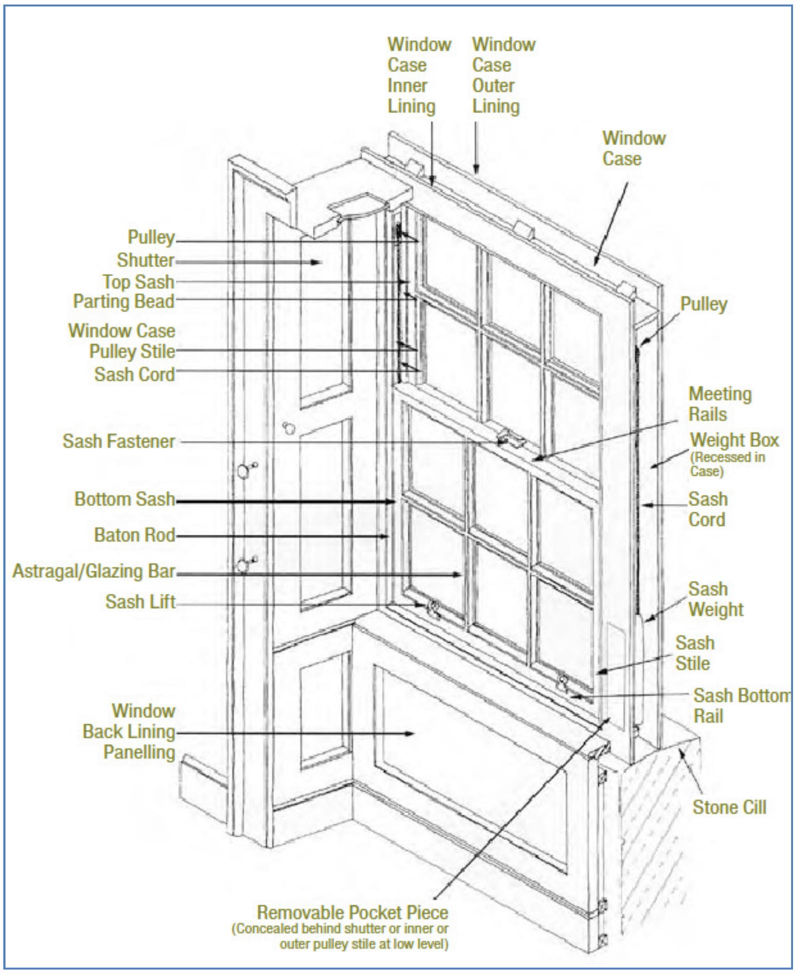

Figure 1 Components of a typical sash and case window[1]

2.1 Windows improvement

Typical timber frame single glazed window may have a U-value as 5.5 W/m²K Improvement measures can be the following:

- Adding draught proofing;
- Adding secondary glazing: U-value lower than 2.3 W/m²K with low-e glazing;

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[1] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

- Adding wooden internal shutters: U-value lower than 2.2 W/m²K (night time solution;
- Replacing the window with modern double/triple glazing: U-value lower than 2.2 and 1.0 W/m²K respectively.

2.1.1 Adding draught proofing

Heat losses also occur through gaps between windows and its frames. There is a wide range of draught proofing technology available, which usually do not arise any issue for historic buildings. A typical system consists of narrow insulating strips: plastic, neoprene in a carrier, carrier-based tubular brush strips or mastic gun-applied sealant.

A more complex system consists of fitting draught proofing in channels integrated in the window frame. This usually involves removal and dismounting of windows.

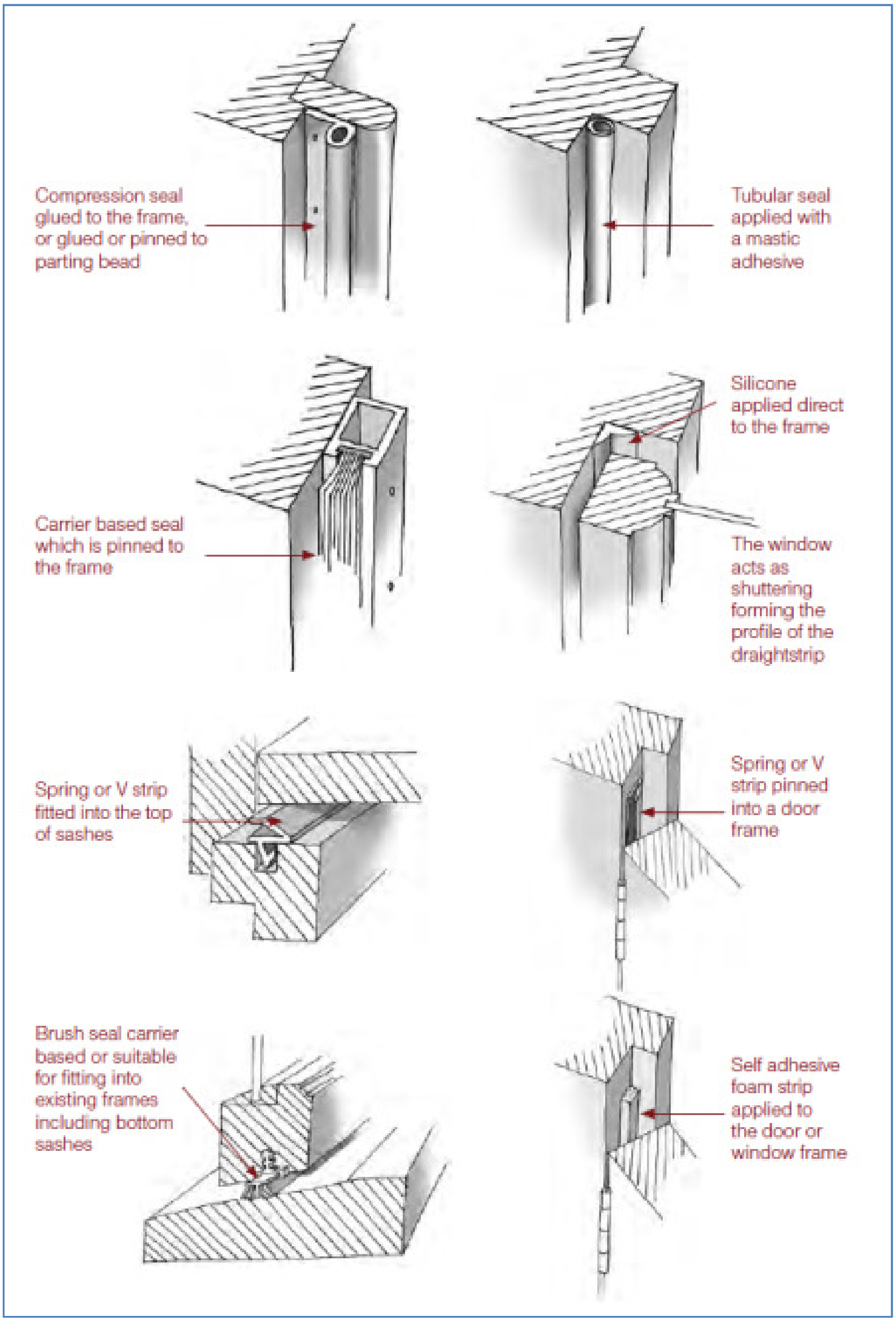

Figure 2 Possible applications of additional draught proofing systems.[2]

2.1.2 Secondary glazing

Secondary glazing has less impact on visual appearance than replacement with DGU or TGU and is usually accepted from a building conservation viewpoint if it does not cause any damage to internal materials and finishing.

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[2] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

Weak points of this solution are the following:

- Intrusion into the room and loss of usable space;
- Increase of visual distorsion due to the double reflection effect visible from outside.
- Need of integration with eventually present curtains and blinds.

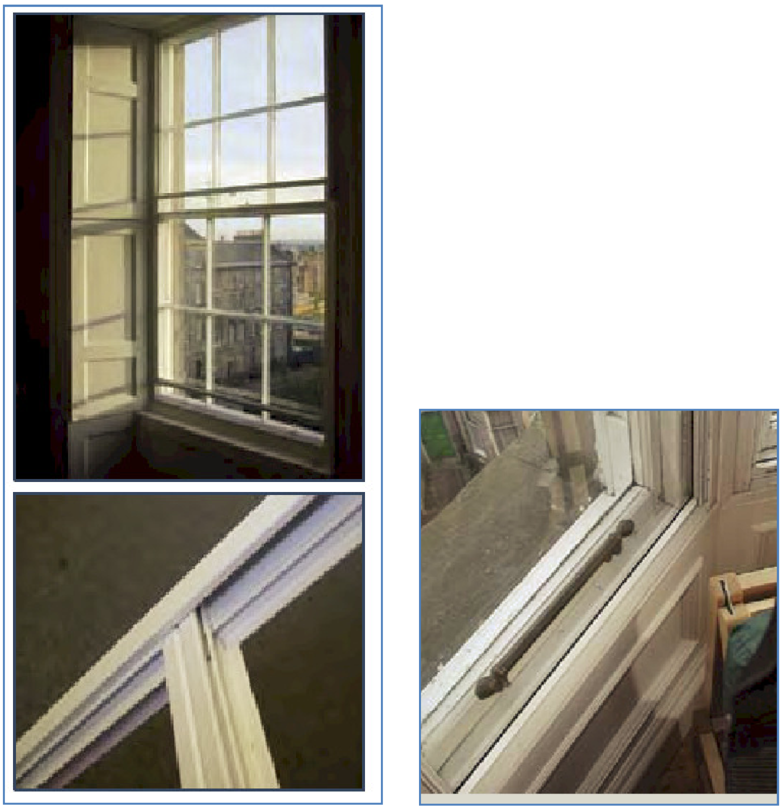

Figure 3 View of secondary glazing installation from inside[3]

Besides, visual impact must be minimised using a complementary style for the secondary window/glazing. The secondary window is usually installed internally with the aim of reducing both radiated heat loss and air leakage. Some examples are shown in the image below.

---

[3] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

Example of clearly visible secondary glazing.
© Crown Copyright, image reproduced

Example of the 'double reflection' caused by some secondary glazing.

Slimline secondary glazing used in the Energy Heritage pilot study (Part C).

Figure 4 View from outside: visible secondary glazing (left), reflections and visual distorsions (centre), secondary glazing without intermediate frames (right).[4]

2.1.3 Replacement

In case of replacement two main components should be considered: glass and frames.

Frames

DGU and TGU have wider and thicker frames than the single glazing unit they replace. In some cases DGU can be fit into existing timber frames, depending on the original dimensions and remaining spaces for rebates.

Glazing

The current manufacturing process of glass panes differ significantly from those used in the past. So, modern glass has a more homogeneous and flat surface and is usually more reflective. Old style glass can be manufactured, but it cannot be used for assembly in double glazing units.
A possible solution would be to save the replaced glass and use in new frames.

2.1.4 Warm Edge Spacers

Heat loss through perimeter 'spacers' used in the construction of traditional double glazed units, is a major contributory factor to thermal performance of glazing systems. 'Warm edge spacers' are products employing plastic or stainless steel alternatives to the usual (poorly performing) aluminium products, which are becoming more common in continental façade construction.

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[4] Energy Heritage. A guide to improving energy efficiency in traditional and historic homes, Changeworks Resources for life and Edinburgh World Heritage, 2008.

Figure 5 Super spacer with improved thermal performance to reduce cold bridges at the glass edge.

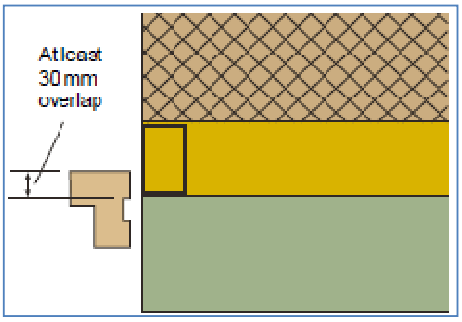
2.2 Window to wall junction

Window to wall junction may cause several problems when replacing windows or external door frames, which have to meet the surrounding and existing masonry wall.
It is of great relevance in refurbishments, when replacement windows are installed in an existing structural opening or when the internal plaster finish of the external wall is to be replaced with internal insulation.
Technical risks:

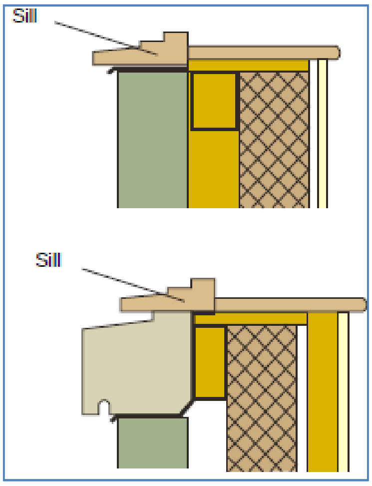
- Condensation and mould at thermal bridges
- Increased heat loss due to air movement
- Mould on reveals due to contact with thermally conductive window frames

2.2.1 Condensation at thermal bridges

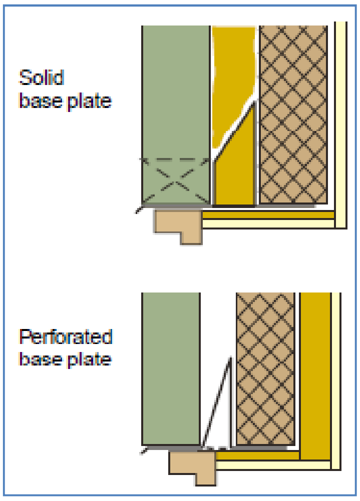
If the continuity of the thermal line is interrupted, the internal surface temperature may fall locally below the dewpoint, resulting in condensation, causing mould growth and damage to wall decorations.
When a window or door frame is set back behind the inner face of a dense outer masonry leaf, it should overlap an insulated closer by a minimum of 30 mm.



In harsh exposure conditions, the frame has to be set-back for its full depth, to be aligned with the insulation layer.
Wall construction shall have a minimum resistance of 0,45 m²K/W. Sills must be insulated as well.



At lintel, a minimum resistance of 0,34 m²K/W should be provided, when realised with a solid base plate; otherwise a perforated plate with a maximum thermal conductivity of 30 W/mK shall be used.



2.2.2 Heat losses due to failing sealing

Draughts and heat losses can be caused by the failure of the airtight seal between the window frame and the wall. Sealing strategy with a primary sealing on the outside and a secondary on the inside are:

- l sealant pointing on the outside and expanding foam or plaster on the inside;
- l impregnated foam strip on the outside and sealant pointing on the inside;
- l sealant bedding on the outside and plaster adhesive on the inside.

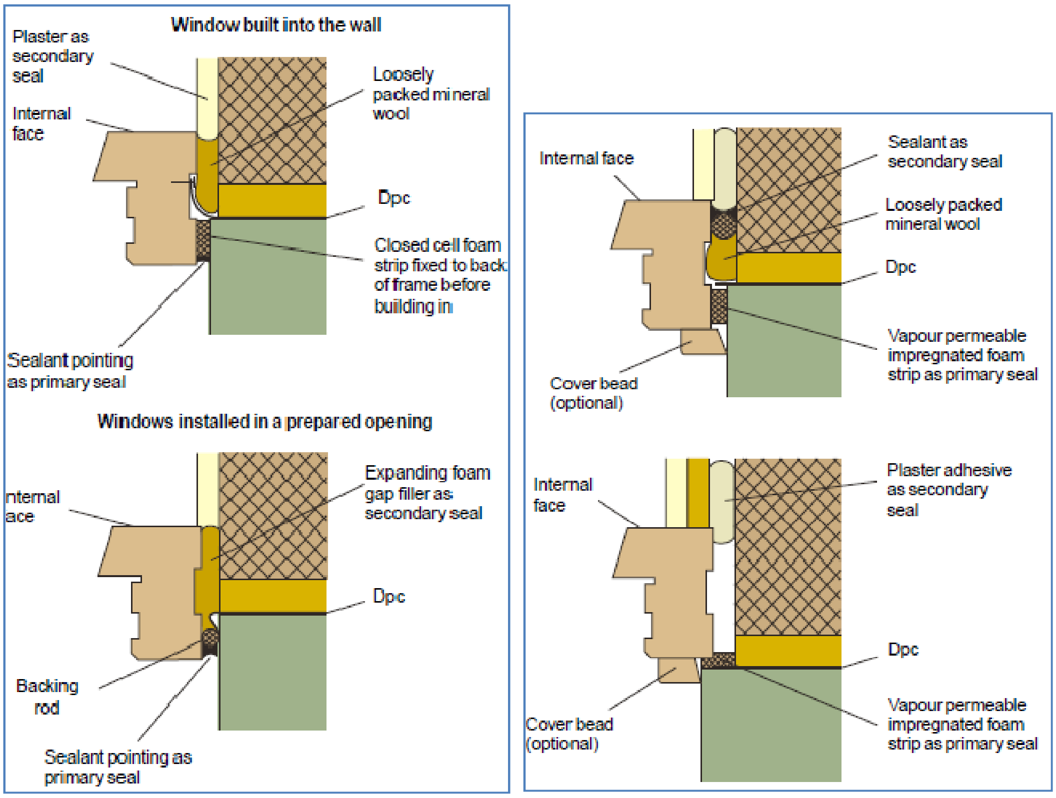


Figure 6 Typical options for sealing strategy.[5]

2.2.3 Mould forming on metal frames

Metal and thermally conductive frames may have condensation suffer from surface condensation forming. If they are close to absorbent finishes such as plaster, it could be cause of mould growth at window reveals.

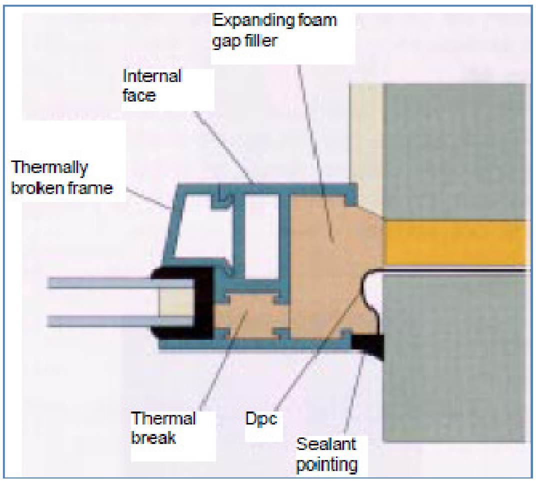


Figure 7 Connection between metal frames and wall/plaster.[6]

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[5]

[6] Thermal Insulation avoiding risks, BRE (C. Stirling), 2002.

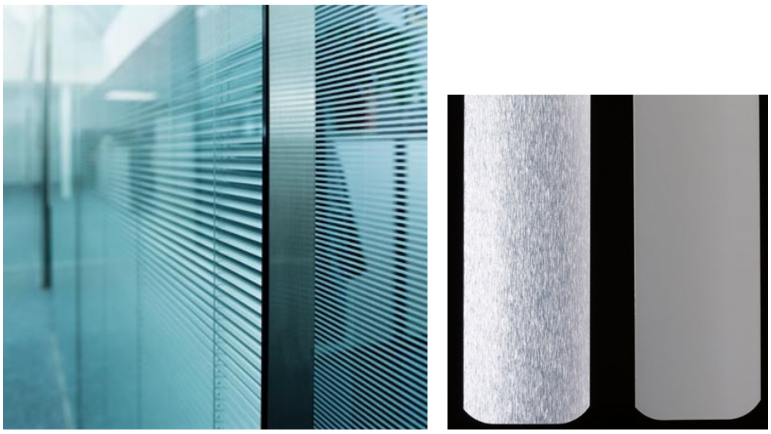
3 Integration of shading system

List of available products and shading devices for integration. Other suppliers are available for most of the listed solutions, providing products which are similar for technology and performance.

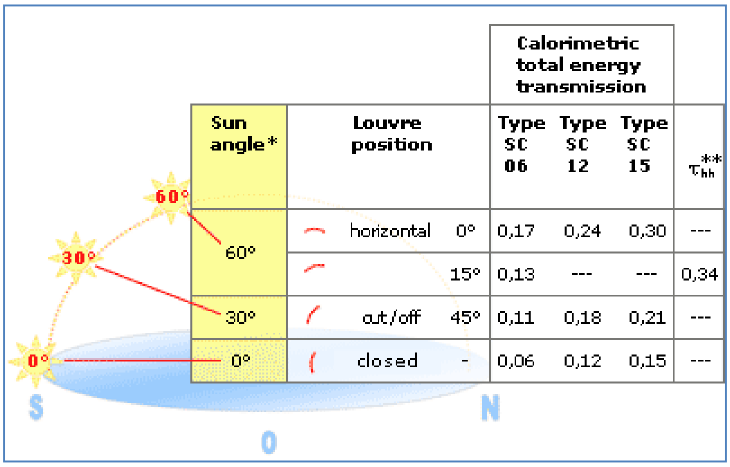
3.1 Integrated slats

3.1.1 Ecklite by Eckelt

Eckelt has a series of standard integrated shading products named Ecklite.

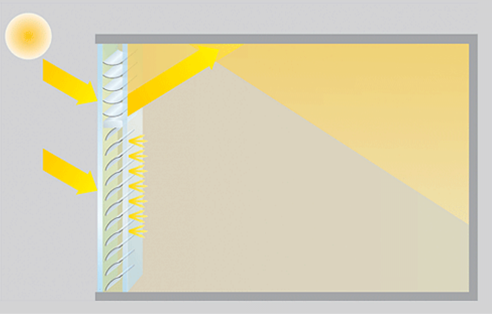


Ecklite SC integrates an electrically operated louvre within the cavity providing solar and glare control. The louvres and other integral parts are thereby permanently protected against weathering and are maintenance free. Typical performance are reported in the table below, referring to a low-e double glazing unit.

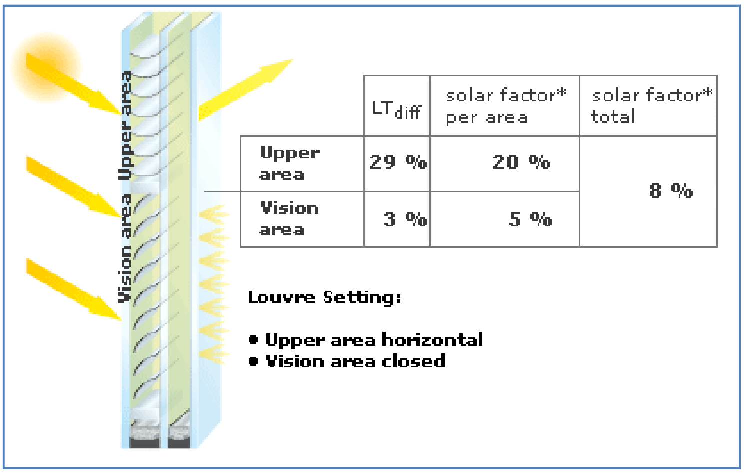


Sun angle*	Louvre position		Calorimetric total energy transmission Type SC 06	Type SC 12	Type SC 15	τ_{hh}^{**}
60°	horizontal	0°	0,17	0,24	0,30	---
		15°	0,13	---	---	0,34
30°	cut/off	45°	0,11	0,18	0,21	---
0°	closed	-	0,06	0,12	0,15	---

Ecklite Evolution integrates two different electrically driven louvre blinds in the cavity. In the upper part of the glass one with a concave section for active light directing and in the vision area one with a convex section for efficient solar and glare control. It is also possible to completely open the louvers in both areas to provide complete and free vision.



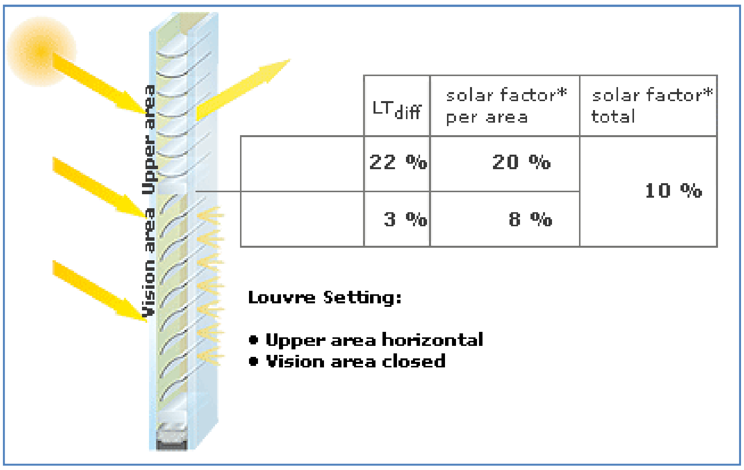
Slats can be integrated in both Triple and Double glazing unit.



	LT_{diff}	solar factor* per area	solar factor* total
Upper area	29 %	20 %	8 %
Vision area	3 %	5 %	

Louvre Setting:

- **Upper area horizontal**
- **Vision area closed**



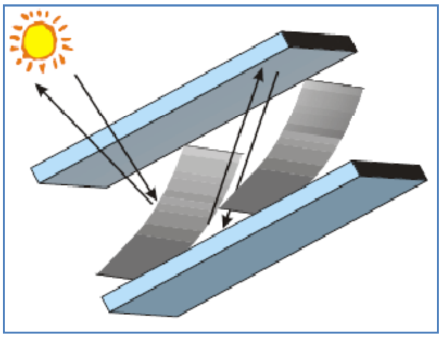
	LT_{diff}	solar factor* per area	solar factor* total
	22 %	20 %	10 %
	3 %	8 %	

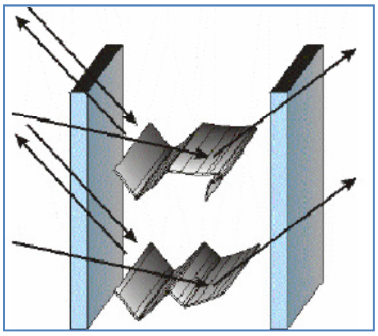
Louvre Setting:

- **Upper area horizontal**
- **Vision area closed**

3.1.2 Okalux: Lamella systems

Okasolar insulating glass is a daylighting system without any moving components. It has direction-selective mirror profiles, which offer a compromise between protection and provision requirements.





Performance Okasolar W

Type	TSET min.	SC min.	TSET max.	SC max	T_v min.	T_v max.	U-value approx.	U-value
	%	%	%	%	%	%	$W/(m^2K)$	Btu/hr/ft^2/°F
OKASOLAR W thermal control coating	18	21	49	57	4	58	1.1 – 1.5 - 1.9	0.19 - 0.26 - 0.33
OKASOLAR W neutral solar control coating	12	14	32	37	4	46	1.0 – 1.4 - 1.8	0.18 - 0.25 - 0.32

3.1.3 Glastech: Screenline

Screenline is a sunshading and vision system controlled by manually operated lamellae Venetian blind installed in the space between the panes. The functional technique of the blind is to turn and / or to raise and lower the lamellae. Different spaces between the panes are possible, 20, 24 and 27 mm.

Main technical features are the following:

- The drive and handling of the lamellae blind are manually operated;
- Colours: thirteen standard colours, special colours upon request;
- Possible combinations with thermal insulation glass, sunshading and facade glasses, screen printed and sandblasted glasses.
- Can be used with frames made of aluminium, steel, timber, timber-aluminium and plastics.

ISO-Shadow is an insulating glass constructions with a lamellae Venetian blind installed in the space between the panes. The functions are sunshading and vision control just as one wishes by raising, lowering or turning the lamellae. The lamellae blind of ISO-Shadow travel from the bottom upwards.

- Drive of the lamellae blind by a high-quality and maintenance-free 24 V DC-motor;
- Control: single or group controls, infrared remote control, temperature or sun light controller, time switches, BUS controls;
- Colours of the lamellae blind: seven standard colours, almost all RAL-colours available;
- Possible combinations with thermal insulation glass, sunshading and facade glasses, screen printed and sandblasted glasses;
- Can be used with frames made of aluminium, steel, timber, timber-aluminium and plastics.

ISO-Roll is an insulating glass with a foil roller blind for sun protection and glare protection installed in the space between the panes of 24 mm. The metal coated foils consist of multi-layer polyester and reflect direct and diffuse sun and energy radiation outwards. The total energy transmission rate (g-value) is reduced up to 9%. The roller blind can be operated up and down and stops in every desired position.

- Drive of the roller blind by a high-quality and maintenance-free 24 V DC-motor;
- Control: single or group controls, infrared remote control, temperature or sun light controller, time switches, BUS controls;
- Foils and colours of the roller blind: foils in transparent or nontransparent design, colours silver – silver or silver – anthracite;

- Possible combinations with thermal insulation glass, sunshading and facade glasses, screen printed and sandblasted glasses;
- Can be used with frames made of aluminium, steel, timber, timber-aluminium and plastics.

ISO-Daylight is an insulating glass with a redirecting lamellae Venetian blind installed the space between the panes of 32 mm. The outer pane of this light redirection system consists of white glass; thus an overall reflection ≥ 85% is achieved. Both the lamellae's special geometry and the alignment of the lamellae as well as the special surface capture diffuse daylight and, over bright and reflective ceilings, redirect it further into the room depth of buildings – shadeless light is guided to workplaces.

The lamellae are made of aluminium with a high gloss finished layer of metallic oxides on the top surface. In order to avoid disturbing an unpleasant reflections in rooms, the back of the lamellae is specially coated with a light grey surface – it blanks out high luminance and prevents multiple reflections almost totally.

The lamellae blind is permanently down, the light redirecting lamellae can be built in either immovable with adjusted inclination angles or with an infinitely variable setting. However, to avoid glaring effects, the turning of the high reflecting lamellae' top sides towards the room side is not possible.

3.1.4 Pellini: Screenline

In the ScreenLine system, the blind (venetian, pleated or roller) is encapsulated within two glass panes. The movement of the blinds can be both manual or motorised and it occurs in a totally sealed environment. If manual, they can be controlled by knob, cord and magnetic removable control. This ensures protection against dirt, dust or weather conditions, and therefore does not require any maintenance. The magnetic components have a loss of magnetic attraction of around 2% per 100 years.

The product choice is wide and the ScreenLine blind system is suitable for all types of framing systems. Blinds area available in three different typologies: venetian, pleated and roller.

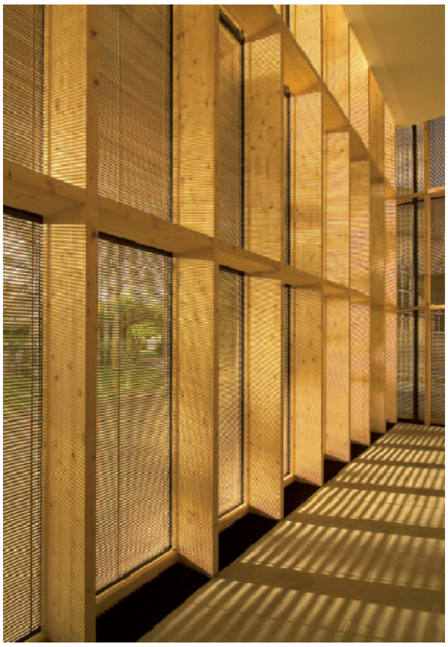
Venetian

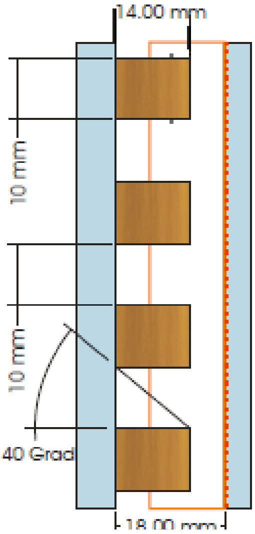
Pleated

Roller

3.2 Integrated timber elements

Okawood is an insulating glass with integrated timber blinds. The built up is similar to Okasol, except for the slats which are manufactured to obtain a timber grid.

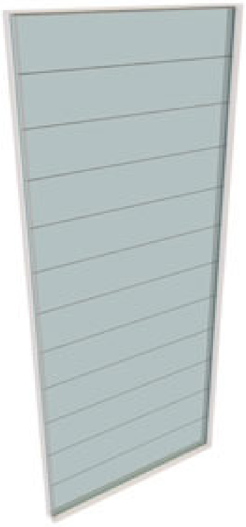


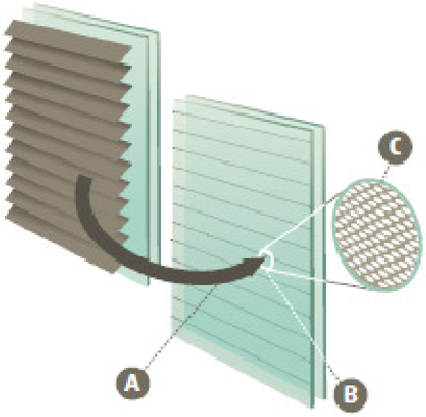


3.3 Wire metal meshes

3.3.1 MicroShade

MicroShade™ is an innovative solar shading system for glass facades. It provides effective and environmentally friendly solar shading for buildings. It is made of micro-perforated stainless steel strips lamellas integrated in double or triple glazing units.





The micro lamellas in the MicroShade™ strip filter the sunlight according to the same principle as ordinary blinds. Sunlight incident at low angles passes through the lamellas while solar radiation incident at high angles is effectively blocked. MicroShade™ solar shading is supplied pre-installed in the insulating glazing unit, which is fitted as a standard glazing unit. The solution is therefore suitable for renovation projects. The MicroShade™ strip can be installed in almost all types of two- or three-layer glazing with any choice of glass type. The windows can be provided with a g-value as low as 0.10, which corresponds to maximum shading. Main features:

- A transparent strip with a transparent micro lamella structure with a standard height of 140 mm and is installed horizontally;
- Same service life as insulating glazing units;
- Same high shading effect as external solar shading;
- No maintenance required;
- Complies with EN 1279 regulations for insulating glazing.

Performance with low-e glass

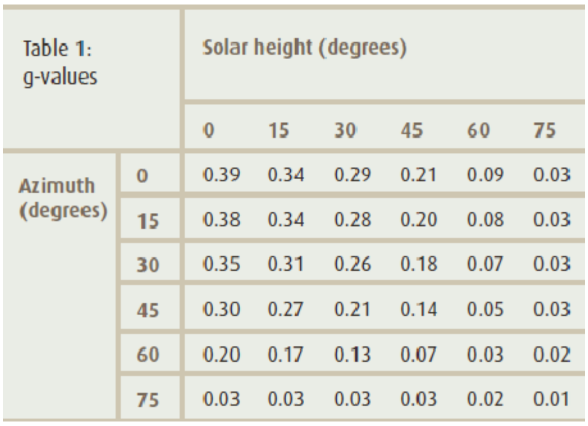


Table 1: g-values		Solar height (degrees)					
		0	15	30	45	60	75
Azimuth (degrees)	0	0.39	0.34	0.29	0.21	0.09	0.03
	15	0.38	0.34	0.28	0.20	0.08	0.03
	30	0.35	0.31	0.26	0.18	0.07	0.03
	45	0.30	0.27	0.21	0.14	0.05	0.03
	60	0.20	0.17	0.13	0.07	0.03	0.02
	75	0.03	0.03	0.03	0.03	0.02	0.01

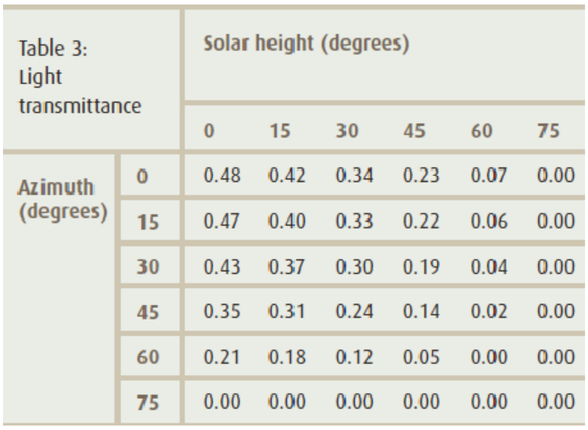
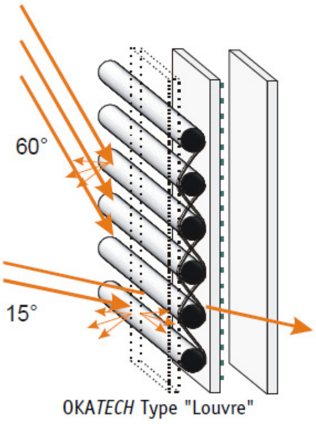
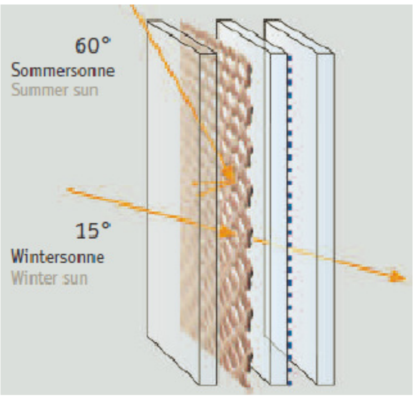


Table 3: Light transmittance		Solar height (degrees)					
		0	15	30	45	60	75
Azimuth (degrees)	0	0.48	0.42	0.34	0.23	0.07	0.00
	15	0.47	0.40	0.33	0.22	0.06	0.00
	30	0.43	0.37	0.30	0.19	0.04	0.00
	45	0.35	0.31	0.24	0.14	0.02	0.00
	60	0.21	0.18	0.12	0.05	0.00	0.00
	75	0.00	0.00	0.00	0.00	0.00	0.00

3.3.2 Okalux: Expanded metal mesh

Okatech is an insulating glass with metal interlayer and can integrate many different designs of wire mesh, expanded metal or perforated metal sheet as a design element with variable functions.

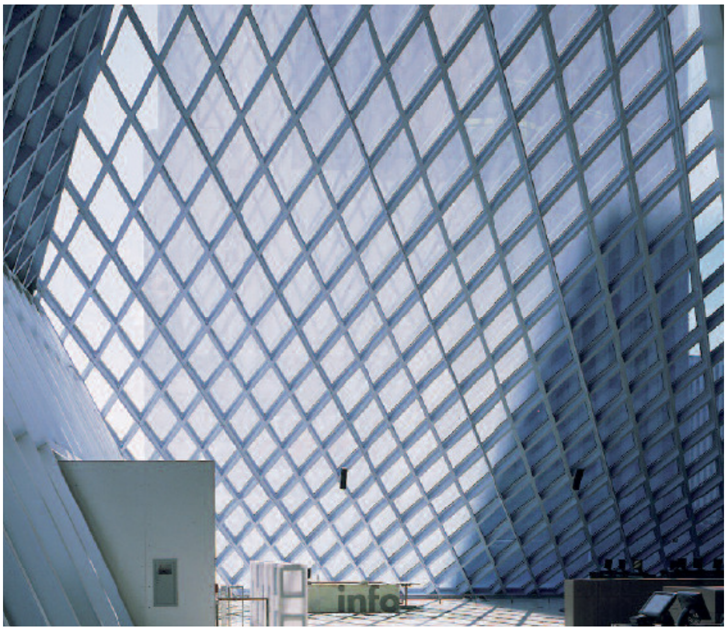




The material and the manufacturing process determine not only the aesthetics but also the function:

- sun protection that can also be directionally selective, depending on the type of inlay used;

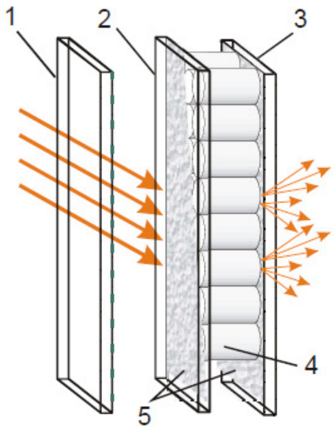
- partial through-vision;
- heat insulation;
- colour and textured shine.



3.4 Capillary systems (diffusing)

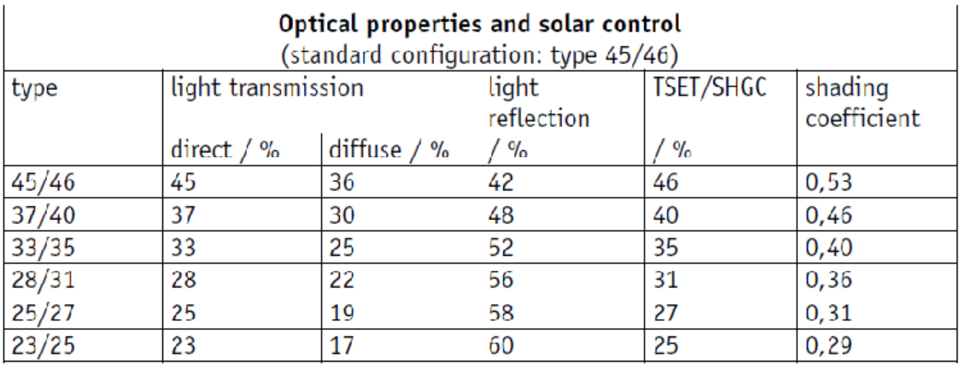
3.4.1 Okalux

Okalux is made of a capillary slab made of polymethylmetacrylate (PMMA), guaranteed UV-stable (light fast) and additional glass fibre tissue. The capillary slab diffuses direct sunlight and creates an even illumination of the room with daylight. Direct solar radiation into the room and thus hard shadows are prevented. Glare problems are significantly reduced.



The capillaries prevent heat transmission in the inner cavity, not only with respect to convection but also in terms of heat radiation.

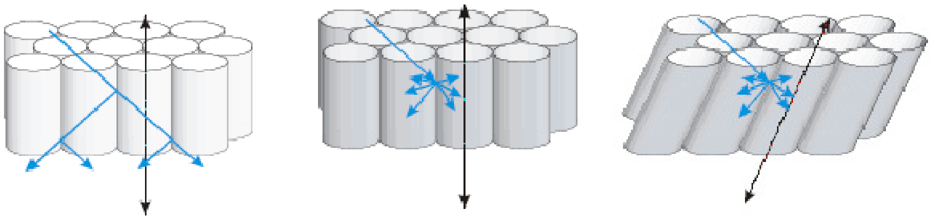
The U-value of various different configurations depends on the control coating on surface 2, the outer cavity (8, 10 or 12 mm); the gas filling in the outer cavity (air/argon/krypton).



Optical properties and solar control
(standard configuration: type 45/46)

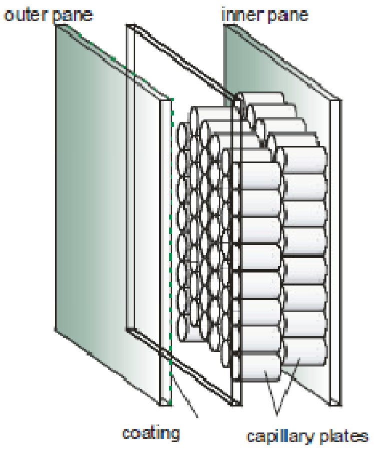
type	light transmission		light reflection	TSET/SHGC	shading coefficient
	direct / %	diffuse / %	/ %	/ %	
45/46	45	36	42	46	0,53
37/40	37	30	48	40	0,46
33/35	33	25	52	35	0,40
28/31	28	22	56	31	0,36
25/27	25	19	58	27	0,31
23/25	23	17	60	25	0,29

Kapilux is an insulating glass with an integrated capillary slab. The type designation "–T" (left side) refers to a capillary slab made of transparent material, "–W" (right side) refers to white-tinted material. “WS” is a directionally selective sun protection system with individually orientable capillary axes. The capillaries do not only reduce heat losses resulting in U-values as low as 0.8 W/(m²K); with their forward-directed light diffusion, they also improve the in-depth illumination of the room. This effect is particularly valuable on overcast days and in rooms with side illumination.

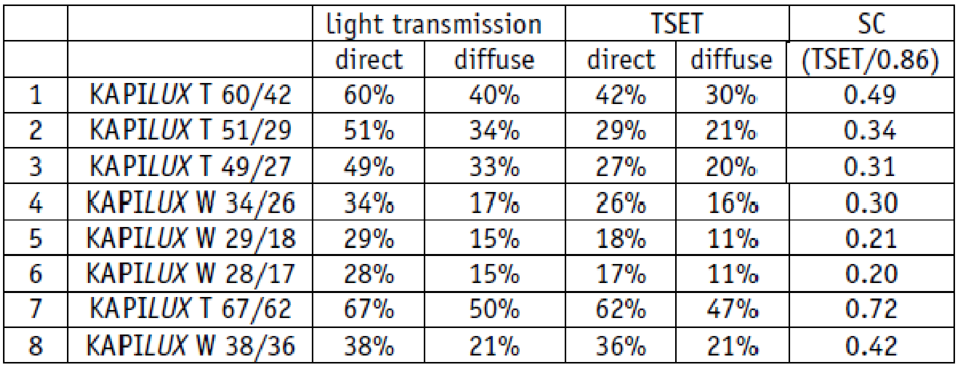


Construction

First gap: 8 mm filled in with gas according to Ug-value requirements
Middle pane: float glass according to static requirements, but at least 4 mm;
Second gap: cavity with insulating capillary-structured transparent insulation made of polymethylmetacrylate (PMMA), UV-stable.
The capillaries diffuse the light and create an even illumination of the room with daylight. Close to the capillary axis, partial through vision is possible.



Performance



		light transmission		TSET		SC
		direct	diffuse	direct	diffuse	(TSET/0.86)
1	KAPI*LUX* T 60/42	60%	40%	42%	30%	0.49
2	KAPI*LUX* T 51/29	51%	34%	29%	21%	0.34
3	KAPI*LUX* T 49/27	49%	33%	27%	20%	0.31
4	KAPI*LUX* W 34/26	34%	17%	26%	16%	0.30
5	KAPI*LUX* W 29/18	29%	15%	18%	11%	0.21
6	KAPI*LUX* W 28/17	28%	15%	17%	11%	0.20
7	KAPI*LUX* T 67/62	67%	50%	62%	47%	0.72
8	KAPI*LUX* W 38/36	38%	21%	36%	21%	0.42

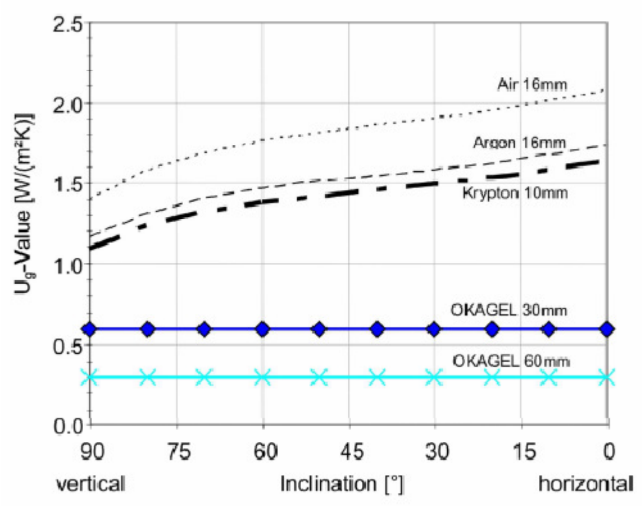
3.4.2 Okalux: Nanogel system

Okagel is a light diffusing nanogel insulating glass able to offer high heat insulation levels. The translucent Nanogel, a nanoporous granulate offers a range of features:

- light distribution into the room, independent of changing irradiation conditions together with glare protection;

- project-specific light transmission and total solar transmittance;
- excellent heat insulation;
- effect of depth when viewed from inside and outside

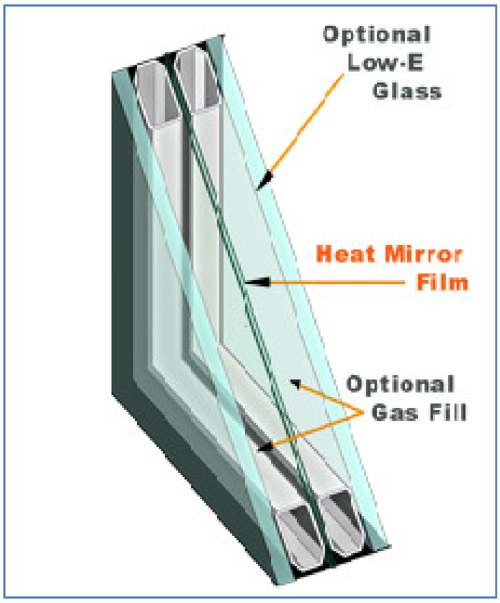
Thermal insulation performance



3.5 Suspended low-e films

‘Heat Mirror’ is a high performance solar film, that can be suspended in the cavity of a double glazed unit. The U-value range is from 1,20 W/m²K down to 0,46 W/m²K, thus providing a performance level even better than a full triple glazing without the addition of the weight of an additional glass panel. Solar factor is 0,40 to 0,27, with a light transmittance always around 0,50.

Heat Mirror units are produced with a wide range of glass products including clear glass, tinted glass and low-e glass, with the benefits of film based coatings and glass based technologies to create high insulating performance and solar control.

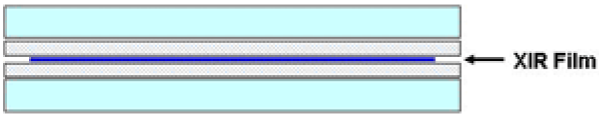


Advantages here include possible incorporation into ‘standard’ sliding door systems, which are designed to accept double glazed units, but cannot accept more highly performing triple glazed units, which are ‘fatter’ and heavier. Currently ‘Heat Mirror’ is 2.0m width. The cost of a DGU with Heat Mirror is ~ 85-120€/m2, according to the configuration. Up to now the system has been used in a few Middle East applications.

3.6 Laminated glass interlayer

3.6.1 XIR film

XIR Laminated Monolithic can be used in vertical, sloped, or overhead glazing applications. From curtain wall to monumental skylights, this technology offers several choices of energy-efficient glazing. XIR Laminated Monolithic can be fabricated in either flat or architecturally curved configurations. By using clear glass panes, a g-value of 0,48 with a Light Transmittance of 0,73 can be used. By using tinted glass as the inner lite, improved solar performance can be achieved.



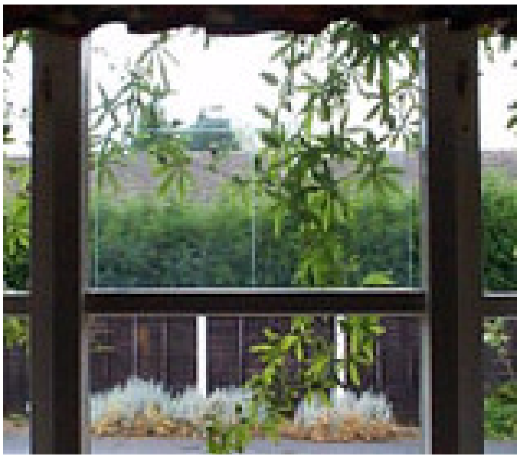
The current width of XIR film is 2.1m. In the next 4-5 years the width should increase up to 3.0m.
XIR - Sentry Glass compatibility. It seems the two materials should not present any major problem in terms of compatibility, but Southwall has not carried out a formal test yet. Even if technically compatible, the real issue is being able to provide the required warranty.
In a DGU, XIR laminated glass can provide improved performance and get g-values as low as 0,33 with clear glass soft coating in face #3 (LT = 0,56). U-value can drop down to 1,66 W/m²K centre pane.

4 Light redirecting devices - Daylighting

4.1 Plastic Film

4.1.1 SerraGlaze

Serraglaze is consists of two very thin sheets of acrylic ("PMMA" or polymethylmethacrylate) incorporating microreplicated prisms bonded together to create microscopic air pockets (“lamellae”) that act as light helves set perpendicular to the faces of the sheet.



The lamellae act like reflecting mirrors when light beams passing through the PMMA strike the surface of the lamellae at an angle greater than the critical angle. This is a result of the change of the refractive index from the figure of about 1.49 for PMMA to the figure of about 1.0003 for air. The critical angle for these two materials (PMMA and air) is about 42 deg. This phenomenon is known as Total Internal Reflection (TIR) and the general behaviour of Serraglaze is that of a beamsplitter, the split ratio of which varies with incidence angle, as illustrated in the Figure.

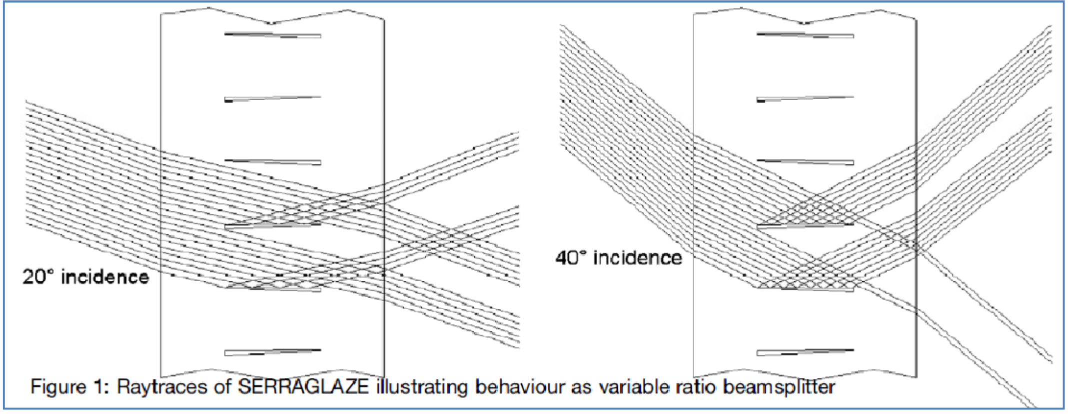
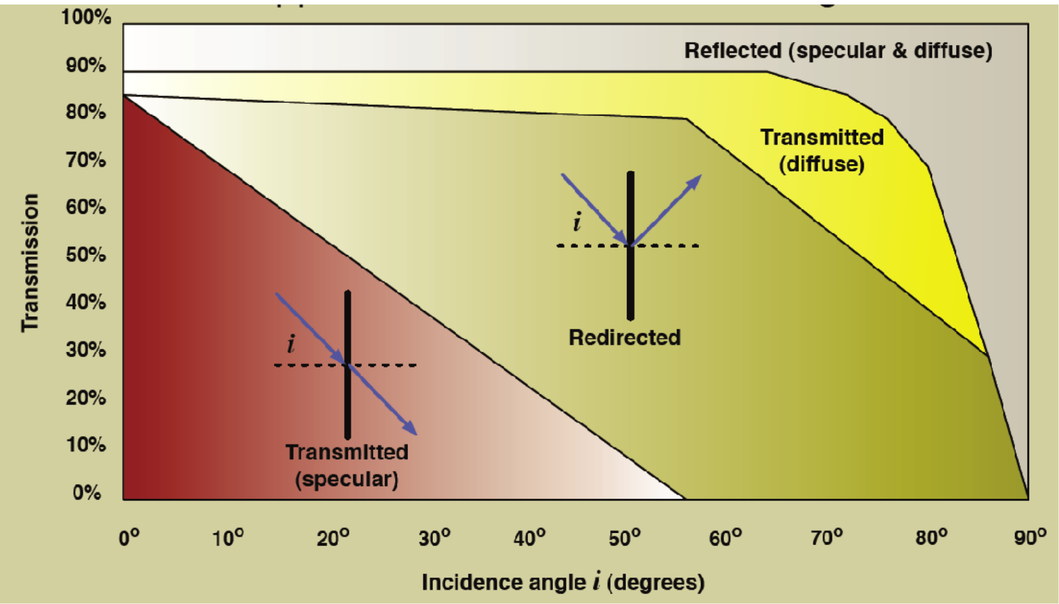


Figure 1: Raytraces of SERRAGLAZE illustrating behaviour as variable ratio beamsplitter

At higher incidence angles than those shown in the figure, the ratio of redirected light to unredirected light becomes larger until, at an incidence angle of around 55°, virtually all the light is redirected and none is transmitted unredirected.

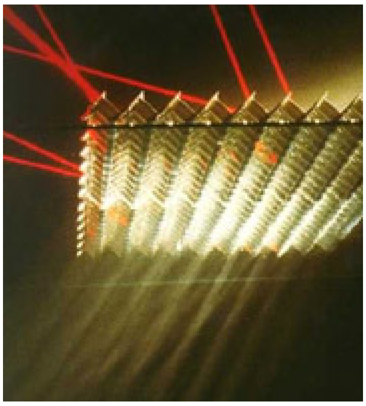


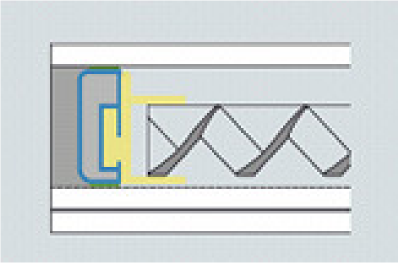
A Serraglaze panel is thin, about 1mm thick, and it is usually laminated between two sheets of glass using optical index matched adhesive and the edges sealed. This provides the necessary protection of the Serraglaze material against damage, dust and moisture. It is made on a bespoke basis using proprietary microreplication techniques by our licensed manufacturer in Germany. Serraglaze is manufactured in 250mm x 250mm panels and smaller panels can be supplied ready cut. To achieve the requisite size, a rectilinear mosaic of Serraglaze panels is made between layers of laminating adhesive that are in turn sandwiched between sheets of glass. The whole assembly is cured in an autoclave in the normal way.

4.2 Complex Prismatic devices

4.2.1 Micro sun shield louvre

This device can reflect direct sunlight from particular directions and allows diffuse daylight from the other directions through. The micro sun shielding louvre prevents the effects of glare from the sun and allows a maximum of 'cool' diffuse daylight to enter. The blocking/admission ratio area of the louvre in relation to the daylight hemisphere is the result of coupling the special construction with the correct setting of the louvre blades to the sun's orbit.





The 25 x 20cm louvre elements have a finish with ultra-pure aluminium within a high vacuum atmosphere. The next step involves connecting the louvre elements to larger units and cutting them to shape and size according to the building location and its architectural conditions. In order to protect the specular louvre from external influences (dampness, dust etc), the inlet is bordered with a special edge profile.

Disc spacing	SZR = 24 mm
Total energy admission level	g = 14%
Light transmission directed	LT = 0 - 55%
Diffuse	LT = 12 - 38%
Colour rendering index	Ra = 97
Coefficient of heat transmission	U = 1,5 - 1,7 W/m²K
Max. dimensions	approx. 2,20x3,00 m or approx. 1,50x4,00 m

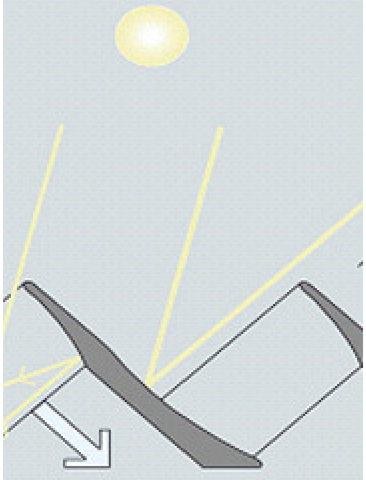
4.2.2 Combisol

The CombiSol sun and glare protection louvre reflects direct sunlight from defined angles back outwards and allows diffuse daylight through from the remaining directions.

The CombiSol louvre consists of two system components:

- an exterior sun protection louvre;
- an interior glare restriction louvre.

The incoming daylight is only let through according to a defined, narrow angle spectrum (65° blocking), so that the glare effect of the glass surface is reduced to suit work activities with computer screens. The 7 x 15 cm louvre elements are given a specular finish with ultra-pure aluminium within a high vacuum atmosphere.

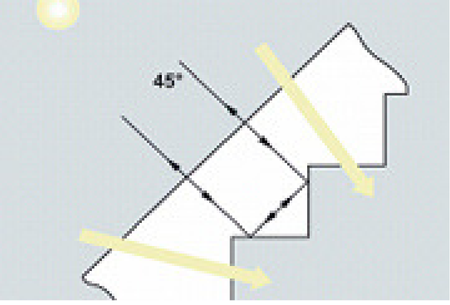


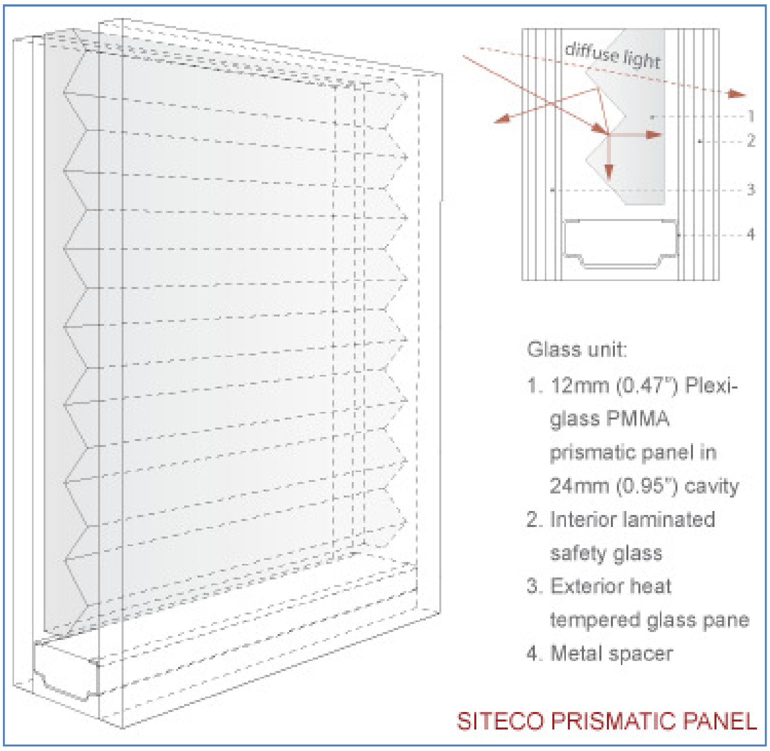
Disc spacing	SZR = 24 mm
Total energy admission level	g = 12%
Light transmission directed	LT = 0 - 45%
diffuse	LT = 13%
Colour rendering index	Ra = 97
Coefficient of heat transmission	U = 1,4 - 1,7 W/m²K
Max. dimensions	approx. 2,20x3,00 or approx. 1,50x4,00m²

4.2.3 Prysm system

The static prism system is a transparent sun protection system for glass roofs that prevents the solar gains from direct solar radiation and at the same time allows the exploitation of diffuse daylight.

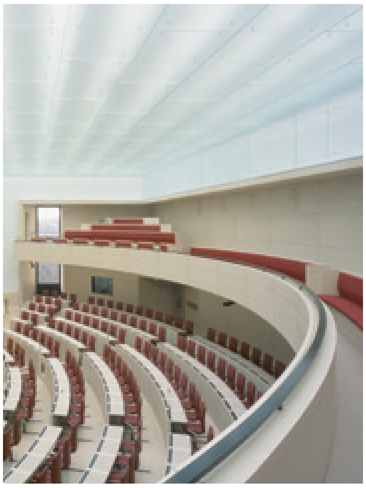
The main objectives are three: the minimization of solar heat gains in the summer, the control of glare without darkening the room, and the improvement of light distribution.





Sunlight protection is based on direction-dependent reflection and transmission with a pre-defined blocking and transmission span. The blocking area of the system reflects all incoming sunlight outwards.

The prismatic system is set according to the progression of the sun across the hemisphere during the day. The 206 x 206 mm prism elements are firstly given a specular finish with ultra-pure aluminium within a high vacuum atmosphere.



dimensions of prism elements	310x750x12 mm
total energy transmittance rate	g =< 12%
light transmission - in horizontal in position	LT = > 54% LT = 74%

5 Sustainability in Operation

Even if it is not a focus point of the project, Sustainability in Operation should be considered while developing strategies and technologies for energy retrofit of historical buildings.

The operation of facade elements such as shading and openings should be intuitive and inclusive. The facade is an essential element in creating and maintaining a comfortable environment within the building, in particular in the perimeter area.

- Thermal comfort: surface temperature to be as similar as possible to the internal air temperature (low U-value of glass, frames), limit draughts, including downdraughts from the façade. Ensuring that replacement or upgraded cladding systems have optimum U-values and air tightness specification. The framing system design chosen is key to this;
- Visual comfort: avoid glare due to excessive light and contrast, provide sufficient daylight levels to perform the tasks required within the building. Ensuring that incident solar energy does not lead to overheating of internal spaces. This is balanced with the desire for the increased use of natural daylight in occupied spaces, with the aim of reducing the use of artificial lighting for tasks in offices in particular;
- Acoustic comfort: reduce noise transmission from outside-in and between floors and adjacent rooms. Acoustic is a subject which will not be developed in the project, but any choice regarding facades will have to take care of this.

5.1 Built Using Sustainable Materials

Embodied environmental impact is the impact of a product, system or process over its life cycle. Commonly referred to as ‘cradle-to-grave’ or ‘cradle-to-cradle’ assessment, Life Cycle Assessment (LCA) can be used to undertake an embodied environmental impact study. Key considerations include:

- Reduce/ Reuse of materials, Cradle to cradle thinking;
- Recycle
- Embodied energy and environmental impact / responsible sourcing

5.2 Climate Change

Climate change will bring with it greater extremes of weather and with these, greater variation to the traditional parameters we design our façades to. The issue must be considered on a regional and location basis but greater extremes in terms of heat and cold, wet and dry, noise, wind and dust are to be expected.

6 Open issues and guidelines

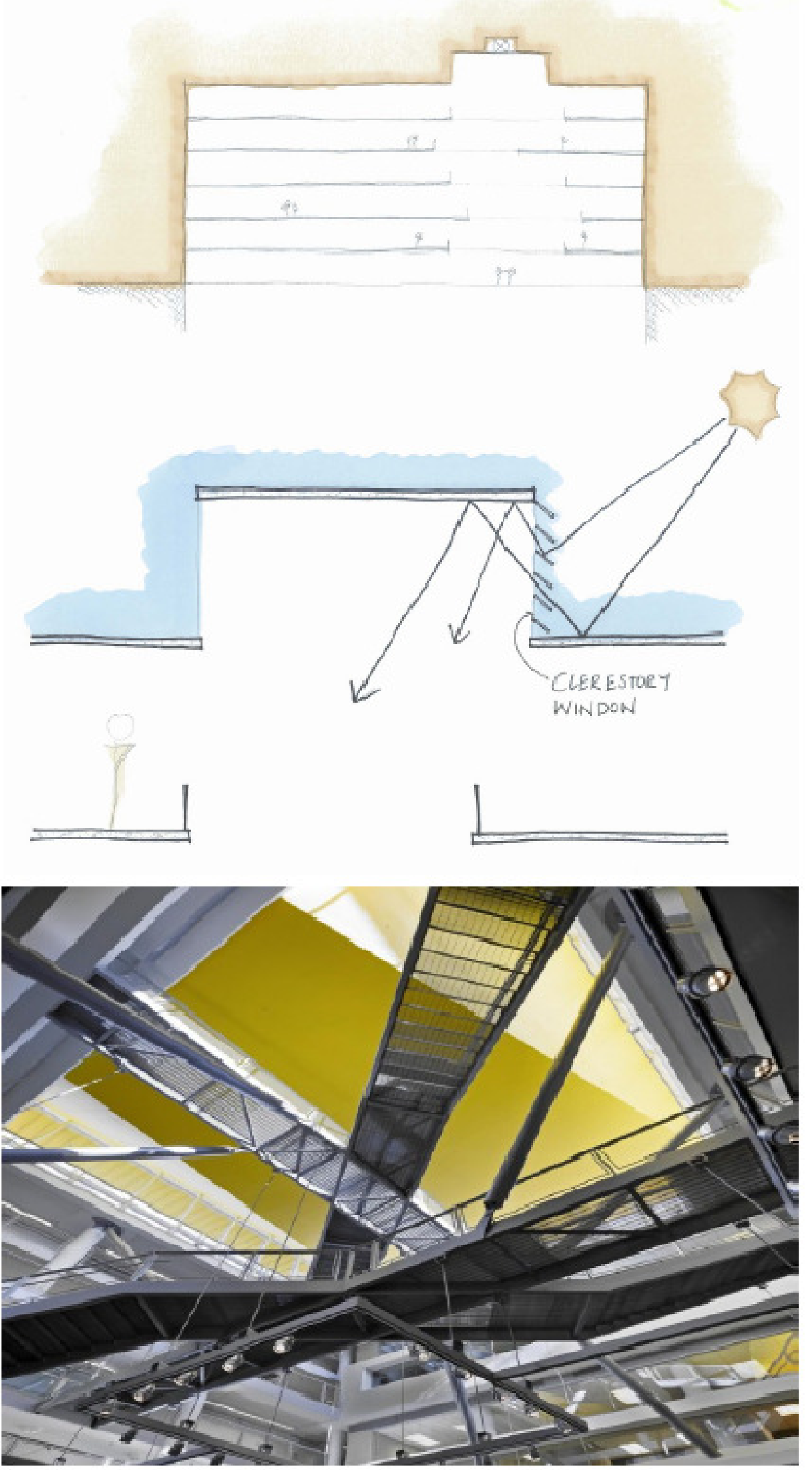
- Possible solutions and limitations for specific technologies;
- Compatibility of modern technologies with conservation requirements, depending on projects, case studies and countries;
- Adaptation/development of existing technologies;
- Dedicated management of Lighting/Solar control devices to meet specific requirements of Conservation (cross to WP4);
- Internal surface development and treatments to improve efficiency and effectiveness of natural lighting.

Appendice A

Atrium shading concepts

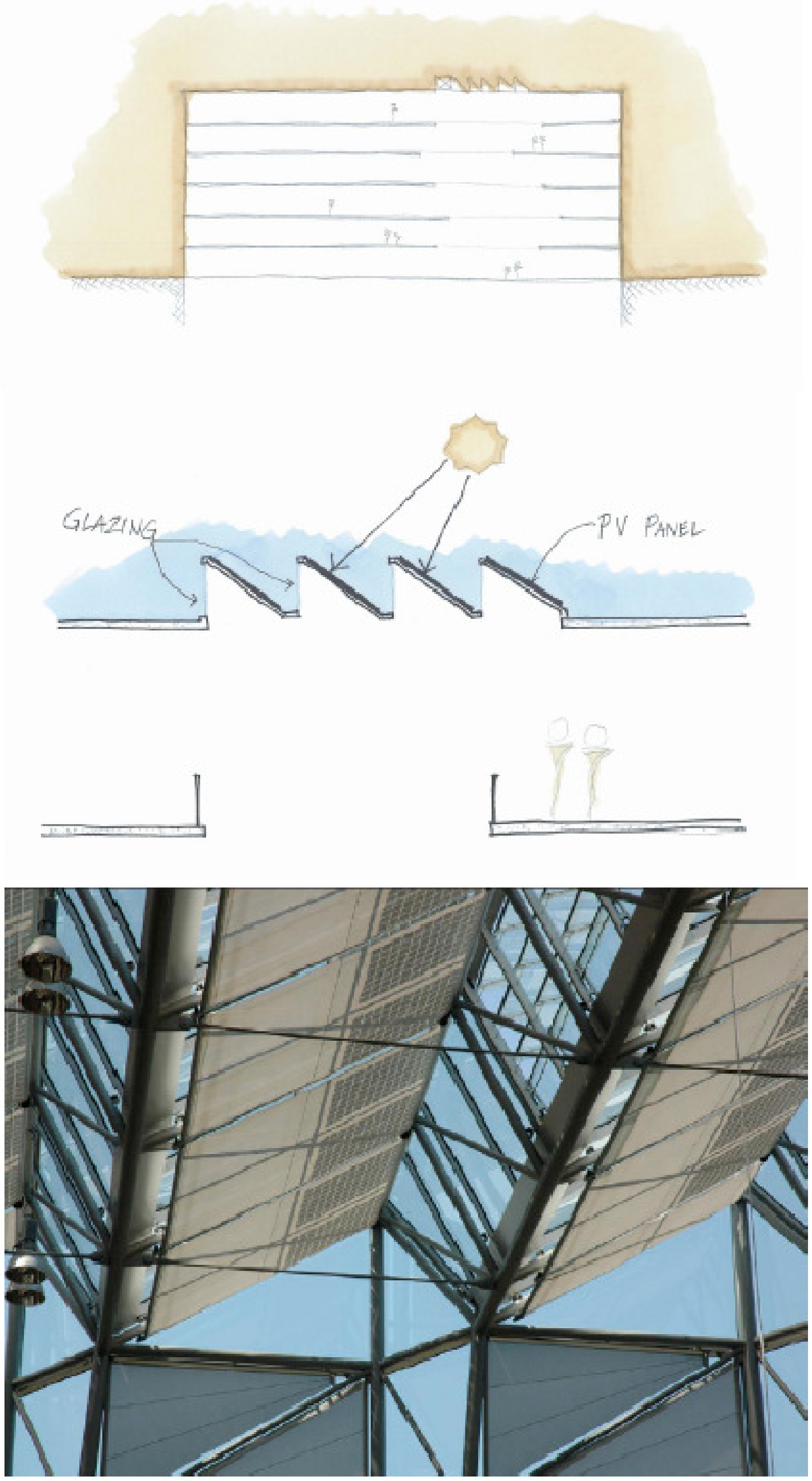
A1 Atrium shading Concepts

A1.1 Clerestorey Windows



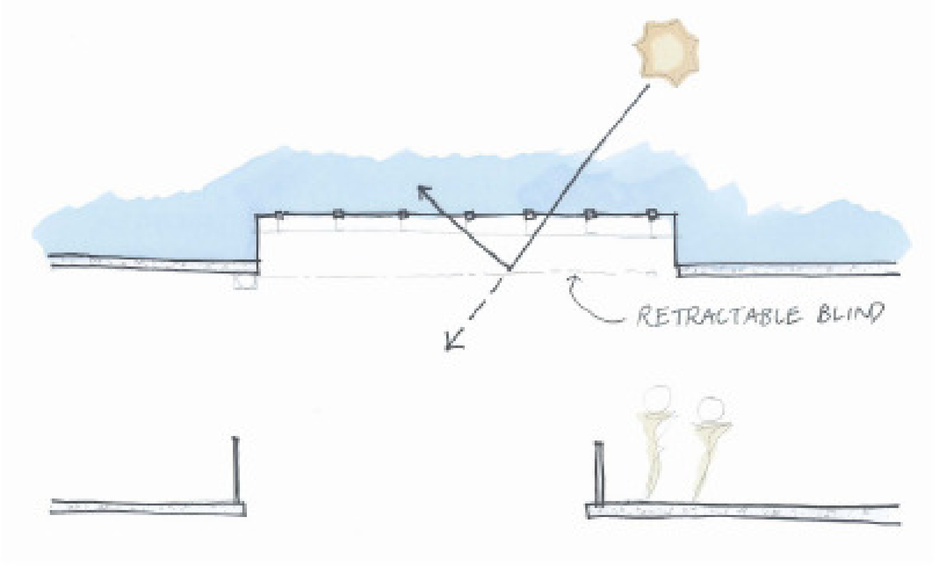
City College of New York School of Architecture, New York, USA.

A1.2 Profiled roof light with PV panels



Umweltbundesamt, Dessau, Germany

A1.3 Retractable or fixed blind

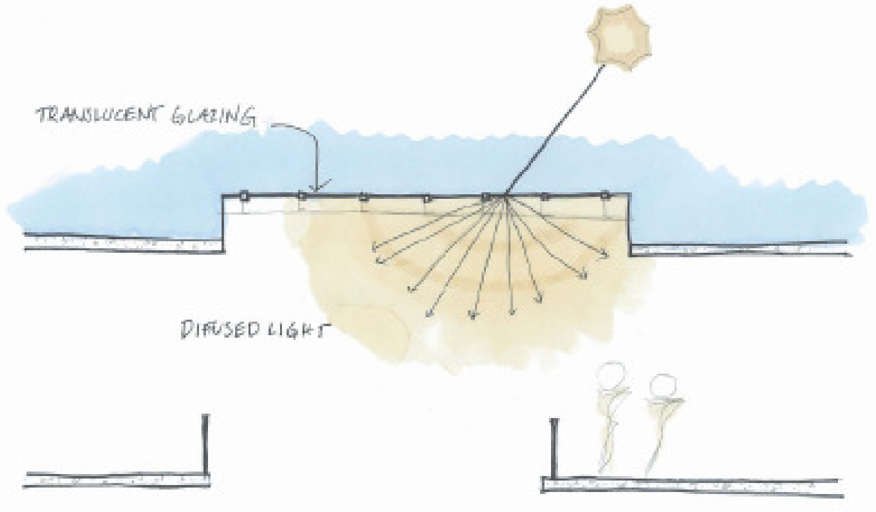


C500 roof at Zurich Airport, Germany

A1.4 Fixed or automated louvers

ANZ Headquarters, Melbourne, Australia

A1.5 ETFE translucent roof lights



White ETFE, Foiltec, Europe