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RESEARCH AND DEVELOPMENT ROADMAP FOR FAÇADE-INTEGRATED SOLAR THERMAL SYSTEMS

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1 Introduction

The project "Aktifas" is funded by the German Federal Ministry for Economic Affairs and Energy. In this project economic, technical and social barriers to solar thermal façades and possible solutions are investigated. Solar thermal façades are meaningful for DHW and other applications due to the more constant irradiation profile throughout the year which avoids overproduction for larger installations in summer. Even more, for combi-systems which also contribute to space heating, the lower altitude angle of the sun in winter in combination with the bigger collector slope compared to tilted roofs is an advantage. The integration of the collector in the building envelope offers possible cost savings compared to the separate construction of the collector and the building envelope. This is due to saved material and saved labour cost. Different distribution channels can offer further future savings compared to the traditional three stage marketing (producer, distributer, installer). Nonetheless solar thermal façades are rarely seen.

In the previous steps the authors have gathered and analysed available products and components for (building-integrated) solar thermal façades [1] and analysed the barriers to the market penetration [2]. In chapter 2 of this publication, the authors define a vision up to the year 2050, which describes the recommended way for the market penetration for these systems. For this scenario, the authors identified the required research and developments with respect to solar thermal façades. Both the vision and the required R&D have been discussed with the participants of Aktifas and other experts working at Fraunhofer ISE in workshops and personal interviews. Chapter 3 presents the technical components, simulations and software engineering, education for practitioners and issues related to the building process, which need to be developed. Previous research and developments have revealed some crucial points for the success of innovative components. The lessons learned and recommendations for development are presented in chapter 4.

1.1 Methodology and process of this Roadmap

The development of SolarActiveHouses (SAH) and building-integrated solar thermal (BIST) collectors has been identified as an important topic for future research and development in the previous "Solar Heating and Cooling Technology Road Map" [3] from the EU's RHC Platform and the roadmap from "Deutsche Solarthermie-Strategie Plattform (DSTTP)" [4]. Unfortunately these documents are not very detailed (i.e. on component level). The target of this roadmap is to give more detailed ideas for R&D in this field and to also prioritize the topics so that public funding can be targeted in this branch. In order to gather the first ideas for R&D topics, the authors organised several workshops and personal interviews with four professors, one manufacturer of traditional collectors, one solar architect and ten experienced researchers from Fraunhofer ISE and EPFL. All the single research and development topics showed that this field is very wide and complex. For the classification and for an even higher degree of completeness, the authors developed the following methodology [5].

1.1.1 Parameter space

After the first collection of topics, the already existing systems (state of the art) were analysed according to their construction. Most of the systems [1] can be subdivided in different subcomponents with certain functions (e.g. the cover, the absorber, a concentrator), whereas the characteristics, the order, the amount or even the existence of the subcomponents can vary between different systems. The parameters of these subcomponents form a parameter space (design parameters) which includes the BISTs that are available today.

The next step was the expansion of the topics of this parameter space to a parameter space which also includes all the physical phenomena that occur. These are the solar radiation (with e.g. the spectrum and polarisation), optics (e.g. transmission, scattering), heat transfer (between absorber, heat fluid, building), hydraulics, vapour transfer, degradation. After that also non-technical parameters such as standardisation, education or the building process were included. The parameter space was organised in a mind map that is shown in the appendix. The structure of this report is based on this parameter space.

1.1.2 Evaluation space

Furthermore, this roadmap offers a prioritisation of the different R&D topics. Therefore a vision and an evaluation space were defined. The vision is based on the visions of previous solar thermal roadmaps [3,4], but focuses on solar thermal façade concepts.

The evaluation of single R&D topics proved to be very difficult especially e.g. regarding the non-technical dimensions of the parameter space. The production cost of a new glazing for instance can be calculated with higher accuracy than the impact of skill trainings for architects. Therefore a rather general approach for the evaluation space has been used. Together with the experts, the following evaluation criteria were defined:

- Functionality
- Aesthetics
- Ecological aspects
- Economics
- Availability/Feasibility

This allows a qualitative comparison of different ideas. In some cases also a quantitative comparison can be possible. Therefore, ideas must be well defined within the parameter space.

The qualitative comparison is a more argumentative way of evaluating the ideas. Therefore one should always keep the problems [2] of these systems and the state of the art [1] in mind. In general, a different weighting or scaling of the dimensions of the evaluation space is possible. In this document the authors tried to use an equal weighting.

A more quantitative evaluation can be meaningful when similar concepts shall be compared. For the evaluation of economics of a system the total cost of ownership (TCO), total investment cost for specific test cases can be compared. Therefore also simulations of the energy gain will be required. Ecological issues can be quantified with the CO_2-equivalent calculated with a life cycle assessment (LCA). This requires a precise definition of the product, its geometry and all the processes that are required for production, transport, operation and recycling. The aesthetics of solar façade concepts can be evaluated with the architectural integration quality that was defined by Munari Probst and Roecker in [6]. This evaluation was used in the catalogue from IEA SHC Task 41 (http://solarintegrationsolutions.org/). Products for building-integrated solar technologies (including PV and PVT) have been listed and the following points were rated with a "+", "-" or "+/-" (neutral):

- Multifunctional element
- Flexibility of shape & size
- Glazing: surface texture choice
- Absorber: surface texture choice
- Absorber: colour choice
- Connection options
- Availability of dummies
- Complete construction system

For this roadmap the authors used the more general qualitative approach (functionality, aesthetics, ecological aspects, economics, availability / feasibility). The structure used in chapter 3 is based on the parameter space shown in the appendix. First the R&D topics within the parameters of the parameter space are identified and prioritised. The result is shown in graphics. After that the different research projects are compared.
This document was corrected and commented in several iterations by the "Aktifas" project partners, the other experts that have been interviewed and by members of the COST action TU1205-BISTS [7].

1.2 State of the art

In [1] the products and solutions for the façade integration have been gathered and categorised. This section will show some highlights and the most common solutions. Most of the installed solar thermal façades, that have been investigated, are rear ventilated customised collectors. Especially for refurbishment, this solution requires customisation of the collectors with individual cases and absorbers that might both have non-rectangular shape in order to fit for example to the geometry of a gable façade. In general, the given geometry of the façade can be a problem for the usability for standard collectors or absorbers, since the manufacturers have automatised especially the assembly of the absorber. The welding process of the absorber sheet to the hydraulics is usually done by one single machine (Figure 1). Only little manual work is required e.g. to connect the meander to the header tube. The production of individual, customised absorbers with these production lines is difficult. Adjustment to those machines is possible in one dimension (length of the absorber) in certain (finite) steps, but this means additional logistical effort in the production process and an increase in the costs. Few smaller companies have specialised on manufacturing customised collectors without automation.

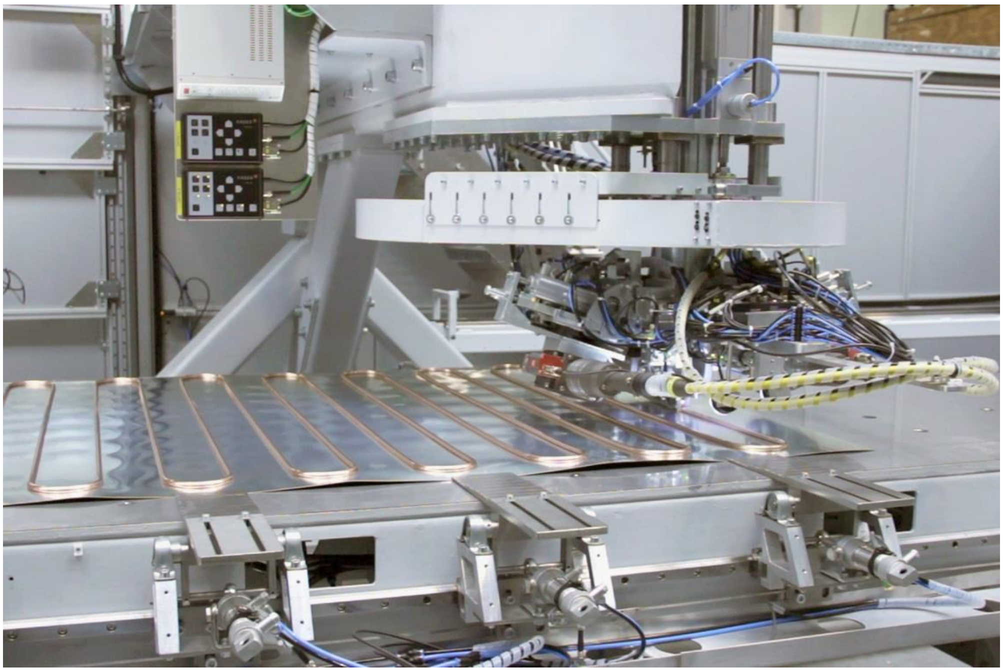


Figure 1: Automatised welding and assembly of the absorber [http://www.tisun.com]

For standard products the trend goes towards thin (thus corrugated) aluminium sheets for the absorber. This and ultrasonic welding at the front surface can give the collector façade a very technical appearance, which might be not appealing, when the spectator is standing too close to the façade. One solution to this can be structured or coated glazing. At the inside of the glass a selective filter is sputtered producing a coloured reflection. The outer surface is etched to have a diffusing layer, which creates a homogenous appearance of the whole surface (Figure 2). The optical losses for these glasses range between 2 and 5 % (http://www.swissinso.com).

Figure 2: Technical appearance of thin absorbers (left) [6] vs. high aesthetical standard due to special glazing [8]

The alternative to hiding the technical appearance of the absorber behind special glazing is to use thicker metal sheets and advanced methods for welding. This can give an even and homogenous appearance of the absorber and regular, solar optimised glasses can be used [9].

Covered collectors have been installed in non-ventilated façades by a few pioneers only (Figure 3). In these projects, absorbers were offered from manufacturers that specialised in customised absorbers. Afterwards they were installed in a timber frame construction made by a carpenter. Due to a lack of education, experience and promotion of this solution, this building process requires a lot of supervision by a skilled architect. The education of architects is treated separately later in this document.

Figure 3: Absorbers integrated in a timber frame construction © Florian Lichtblau, Lichtblau Architekten

Other solutions especially for refurbishment are large prefabricated façade elements that are mounted with a crane. Theses have been used sometimes with integrated solar thermal collectors and in a few cases with transparent thermal insulation [10].

Uncovered systems offer more freedom for architects than the dark highly selective coatings used in glazed collectors. Commercial products are available in a big range of colours and have been used in several buildings. Air [11] and liquid [12] heat transfer media have been used.

For vacuum tubes, the strongest aesthetical barriers were found especially among architects. The balcony and the balustrade can be an option [13]. The first special collectors for façade integration have been developed in the context of national and European projects. Two solutions, shown in Figure 4, are both semi-transparent. The left one uses vacuum tubes with semi-transparent concentrator optics, while in the second one, the absorber with its bended slats is installed within an integrated-triple-glazing-unit. Both concepts have been tested and installed on demo buildings only up to now.

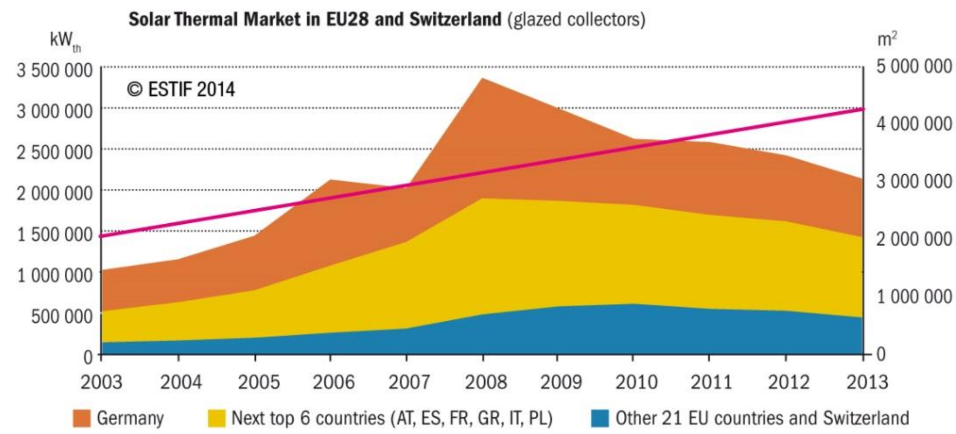
Figure 4: left: vacuum tube collector using a semi-transparent concentrator [14], right: semi-transparent absorber integrated in a glass façade [15]

For new stakeholders, it is difficult to get first estimates for sizing the solar thermal façade system, for the energy performance and costs. The influence of an absorber, which has been integrated in the wall structure, on the heating demand or the requirements for the insulation (thickness) have been simulated only for certain wall structures in scientific projects [16–23,23]. Especially for refurbishment, one can find very different wall structures. The thermal coupling and the vapour transmission have been investigated only for some typical façade structures. Questions according to permanent shading due to changing environmental conditions e.g. growing plants or new buildings in the neighbourhood have not been answered yet. However, the measurements and simulations from Bergmann & Weiß [16] in five different wall constructions have not revealed problems with building physics.

For façade-integrated collectors and conventional collectors, that are mounted with a tilt angle of >75°, a permission due to the building legislation is necessary in Germany [24]. In general, standards for multifunctional collectors (integrated) in a façade have not been developed yet.

1.3 Situation of Market

This section is mainly based on [25]. In 2012 and 2013 the installed collector area in the EU and in Germany decreased by 11 % compared to the previous year (Figure 5). This reveals the challenges that the solar thermal sector is facing. The standard for one and two family homes are collector fields with an area of 5 m² and 12.5 m² for DHW and combi-systems with space heating respectively. Larger installations of around 30 – 40 m² are mainly used for agricultural and industrial applications.



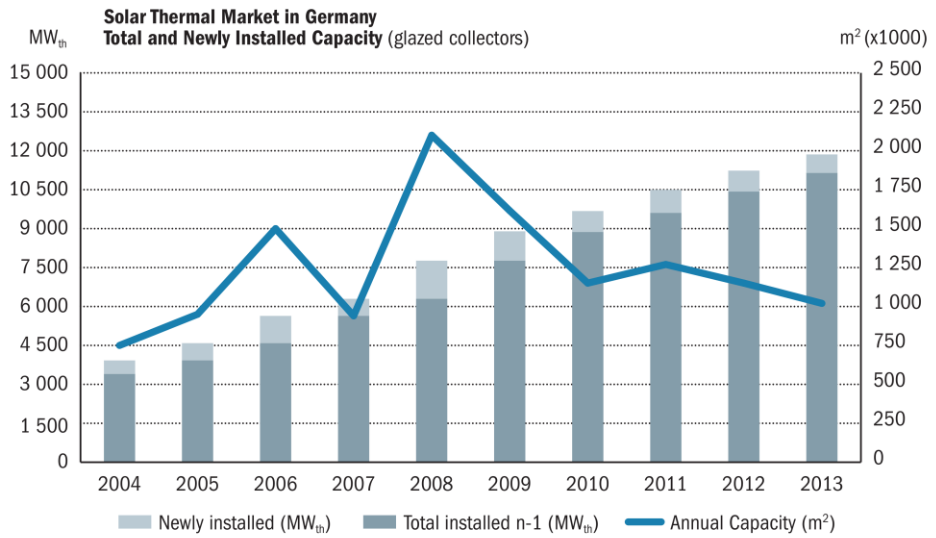


Figure 5: Solar thermal market in Europe and Germany [25]

The cost of ST systems have remained stable throughout the past years [25], while PV systems cost has halved from 2007 to 2012 [26]. Due to their experience and the frequent collaboration with the industry, the authors assume 480 €/m² for an installed collector field and 1000 €/m² including the piping and the tank. There is only little scaling between larger and smaller installations due to different machinery that is needed for the installation of larger plants. The distribution relies on a three-stage system (producer, distributer, installer) [27]. This means that a wholesale dealer distributes the components from the manufacturers to the installers. The major part of the costs remains at the dealer and the installers.

In the sector of single family homes, the strongest competitors are currently systems with a combination of PV and heat pumps because of the strong prize reduction in PV in recent years.

Unfortunately the amount of façade installations remains unknown. According to the authors' experience, this number seems to be very small.

1.4 Applications

Up to now the most common application of solar thermal energy has been domestic hot water and systems combined with space heating in residential buildings [28]. In order to achieve renewable energy system, it will be necessary that also non-residential buildings produce renewable heat. For building-integrated façade solutions this means that new collector concepts will be necessary to be integrated into large glass façades. As described above, solar thermal façades have benefits compared to roof installations. Especially for high-rise buildings, the area on the roof is limited and mostly occupied by the building services. It might be desired to capture the higher summer gains on tilted roofs for PV. Office buildings have very little DHW demand in summer. Here other applications such as dehumidification by solar heat instead of a compression chiller can become attractive.

2 Vision for ST Façades

In [29] the economic potential of building-integrated PV (BIPV) in urban areas was calculated. In the investigated case, the façades provided almost triple the area of building roofs, but contributed only to 13 % of the economic potential of the investigated urban area. Taking the irradiation profile of roof and façade areas into account, it seems reasonable to install PV on roofs, since large solar thermal installations on roofs will lead to an overproduction in summer. The heating demand has its peak in winter, when the profile angle of the sun is low, which leads to a better match of demand and supply for façade installations of solar thermal collectors.

In [30] the potential of solar thermal for low temperature applications in Europe was investigated for three different scenarios (business as usual, advanced market development and full R&D and policy scenario). For Germany and regions with similar climate conditions, the heating sector was identified to be a major market for solar thermal. An area of approximately 17 km² has been installed by the end of 2013 in Germany (numbers taken from Figure 5). Depending on the scenario, [30] anticipates, that an area of 41 – 124 km² solar thermal collectors (contributing 1.5 – 5 % of the low-temperature heat demand) will have been installed in Germany up to 2020. Up to 2030 an area of 107 – 331 km² (contributing 4 – 15 %) is expected to be used and 165 – 662 km² (contributing 6 – 34 %) for 2050 respectively.

The German roadmap [4] hopes for solar thermal to be the least expensive heat source for low-temperature demand and that SolarActiveHouses (SAH) have become the most common buildings up to 2030. By 2050 an ambitious coverage of 50 % of the heat demand by solar thermal energy is assumed.

The RHC-platform's documents [31–35] expect renewable energy to contribute 25 % of the European heating demand. The cost of solar heat is expected to halve due to an increase of 10 % for the efficiency and a 40 % cut in the investment cost. Up to 2030 it is expected that solar thermal will contribute 15 % of the low-temperature demand. This corresponds to the full R&D scenario from [30]. The RHC-platform aims for a 100 % renewable and cost competitive system by 2050.

The composition of such a 100 % renewable energy system was investigated for Germany in [36,37]. It was shown, how Germany can cover most of its national energy demand for electricity and heating (without fuel based traffic and industry) using only renewable sources for optimised annual costs. There are several solutions with similar economic cost than for the current nuclear fossil energy system. A renewable energy system can therefore indeed be cost-efficient, especially if the prices of fossil fuels increase. In most of these advantageous cost-effective solutions, solar thermal energy plays an important role. Three scenarios with different boundary conditions that also showed a different degree of energy savings (retrofitting) were analysed in more detail. The more the energy demand is decreased by energy efficiency measures, the less solar thermal installations are required. The required capacity (or collector area) can be calculated with the numeric results from the paper. The installed capacity for solar thermal collectors ranges from 90 to 170 GW (128 to 242 km² collector area) in the three scenarios. The produced solar energy makes up 16 to 20 % of the heat demand. This corresponds with the RHC-platform's estimations and the full R&D scenario from [30] already for 2030. In the investigated scenarios most or all of the areas required for PV and ST are available on buildings as shown in Figure 6. With the previously given arguments it seems more meaningful to install PV on roofs and ST on the façades. In [30] an even higher estimation of 485 km² for suitable façade area in Germany is given. The required areas (also for PV) lie in the range of the available areas. Reversely, this means that most of the suitable areas need to be activated for solar energy exploitation.

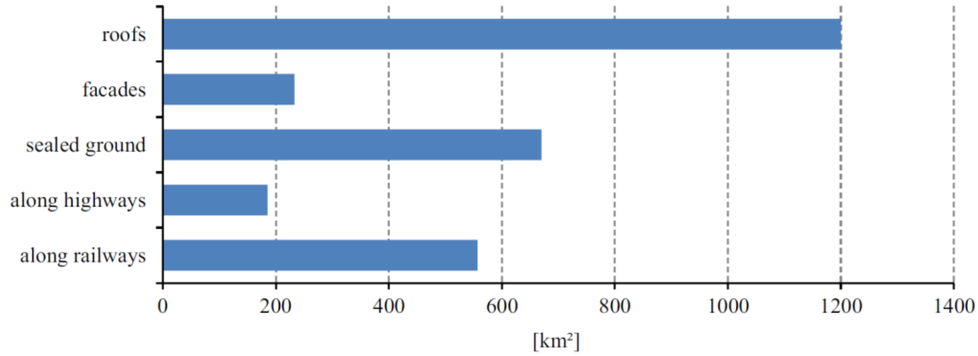


Figure 6: Potentially available area for the installation of systems for conversion of solar energy in Germany (solar thermal or photovoltaic systems) [36,37].

An estimation of future cost of façade-integrated collectors is difficult since only very few pilot installations are known. At the beginning of the Aktifas project, the authors expected customised façade-integrated collectors to be more expensive than standard products. However, such installations have been realised at a cost of 250 – 360 €/m² which is 25 % to almost 50 % cheaper than standard installed collectors (480 €/m²). This was shown in [2] (see also Figure 3). On one hand, the cost savings seem to be influenced by the different sales process without the three-staged distribution with a wholesales dealer. On the other hand, a carpenter has built the whole collector façade instead of separate building processes with stucco-worker for the façade and a solar thermal installer for the collector in the case of building-attached solar thermal. Thereby cost for labour and material can be saved.

With this potential cost savings, building-integrated solar thermal must be considered as one of the key factors in order to exploit the potential as described above and help the solar thermal industry. The strongest competitors are expected to be more and more inexpensive PV systems and heat pumps for smaller buildings and centralised solutions (heat networks, combined heat and power, larger heat pumps) for urban areas.

Based on the numbers presented in this chapter, the references and on their experience, the authors came up with the following vision for solar thermal façades and discussed it with the experts from the Aktifas project.

2.1 Up to 2020

By 2020, flat-plate absorbers integrated in the partly or fully prefabricated façade for refurbishment and new buildings will have been turned into a mass-produced product by a network of collector manufacturers and building companies. These networks can allow different business models and distribution systems (without wholesales dealer), which will lead to lower cost for the investment. The biggest market will first be DHW and combined heating systems for residential buildings, since these are also todays most established markets. Prefabricated houses offer BIST as one solution to meet the energy standards. It is not ambitious to assume investment cost for the collector of 50 % of todays cost, since this has already been realised in certain projects. The authors expect these inexpensive solutions to be well established in SolarActiveHouses with solar fraction of 50 % or more. In the non-residential building sector, the first commercial installations with similar technologies are expected for buildings with a high heat demand (hotels, hospitals).

Very aesthetic products and special façade collectors (air collectors, semi-transparent, switchable) are expected to be demonstrated for applications in niche markets (drying of holiday homes, sky scrapers in Dubai, etc.).

In order to support architects and installers, guidelines to match the most common wall structures in case of refurbishment and new residential buildings have been written and integrated into the daily routine. The complexity and variety of systems has been reduced to only a few standard (best practice) cases. This means that installers or building companies can easily cope with the dimensioning of façade collectors and tanks for the most common buildings (SFH, MFH, etc.).

Since the "solar thermal façade industry" first needs to establish itself, the share of the total heat demand covered by solar thermal façades must still be considered little by 2020.

2.2 Up to 2030

BIST has become one standard solution for most refurbishments, particularly for new residential buildings and hotels and hospitals. Most new residential buildings are SolarActiveHouses with high solar fraction.

Very aesthetic products and special façade collectors have become mass-produced products in their niche markets. This includes a management of the irradiance on the building skin including a solar thermal contribution and an interaction with daylighting due to collectors with adjustable transparency e.g. in office buildings. This also corresponds to the RHC-platform's objectives identified in [33]. The authors expect the residential sector to demand the previously more expensive aesthetically appealing products due to lower prices because of mass production.

Under the assumption that the energy system is changing towards a system as described by the scenarios in [36,37], also more heat networks are expected to be built in urban areas. In that paper, a fraction of 19 – 27 % (more for higher retrofitting) of the collector area accounts for centralised heat. The authors expect that building-integrated collector fields will also support neighbouring buildings with renewable heat and that first projects with urban energy planning have been demonstrated.

2.3 Up to 2050

Assuming a mostly renewable energy system, it is expected that 20 to 34 % of the heat demand are covered by solar thermal based on the scenarios described above in this section. Therefore, SolarActiveHouses with high solar fractions have become the standard also in the building stock. The authors expect BIST to contribute a large part of the buildings' heat demand, due to its technical and economic advantages.

BIST and heat networks have been implemented in a national or international renewable energy system. Therefore solar engineering must have become a regular tool for urban planners.

UP TO 2020	UP TO 2030	UP TO 2050
• (partly) prefabricated solar thermal façades available as mass produced products, also in prefabricated houses • New business models • Cost 50 % of today • BIST first established in residential sector (SAH with 50% solar) • First commercial solar façades for hospitals, hotels, etc. • Special collectors demonstrated for niche markets • More know how among architects and installers, less complexity	• BIST is one standard solution for refurbishment of residential and non-residential buildings with high heat demand • SolarActiveHouse with high solar fraction has become the standard for new buildings • Mass production for special collector façades (semi-transparent, switchable) • First heat networks with BIST demonstrated	• SAH with high solar fractions as standard for building stock • 20 - 34 % of all buildings heat demand covered by (BI)ST • BIST and heat networks integrated into national or international energy system • Solar engineering as standard tool for urban planners

3 Research topics

The structure of this chapter is based on the parameter space as described in section 1.1.1. The parameter space has been structured in a mind map. This is shown in the appendix. At the end of each subsection the single research topics for each parameter are prioritised according to the evaluation criteria described in 1.1.2. At the end a prioritisation comparing the different research topics is presented.

3.1 Basic physical principles

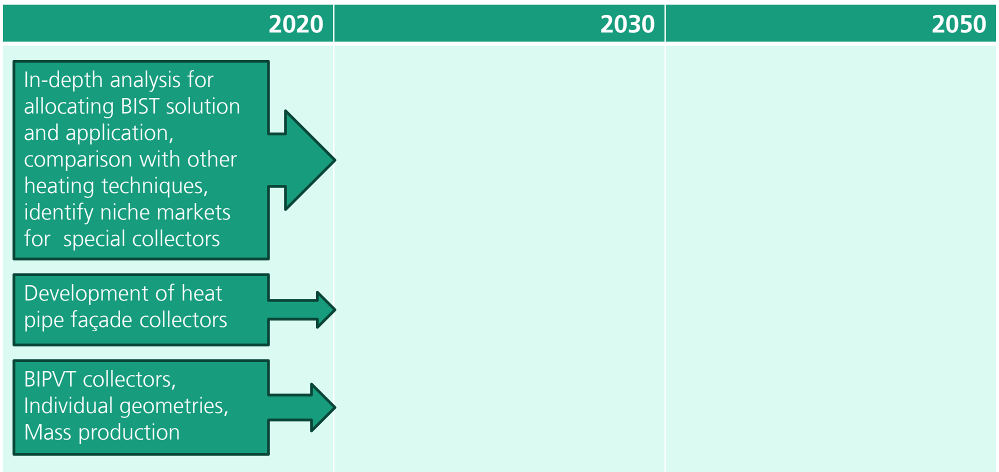
This first part of the parameter space lists the physical phenomena that occur for BIST. The details can be seen in the appendix. Improvements of single physical mechanisms (like the transparency of the cover, polarisation, new absorbing coatings, etc.) can be considered fundamental research. Inventions, which improve e.g. the efficiency, might also be inspired by developments in other industries. This potential is very hard to estimate. Therefore, the approach of the roadmap is dedicated more to applied research. Single research topics that were brought up for certain physical principles were integrated in the rest of this document (e.g. transparency in the subsection about glazing). However, thinking about the physical principles behind BIST can help creative minds to come up with new inventions or new applications.

3.2 Choice of technology

Mainly three technologies have been established on the solar thermal market. Todays standard products use evacuated tubes, covered flat-plate collectors or unglazed collectors with a lower efficiency for higher temperatures. The choice of the technology has the highest influence on the appearance and the reached temperatures. The standard flat-plate collectors have a typical unit area of approximately 2.5 m² with either meander or harp shaped hydraulics connected to a header tube within the case of the collector. Todays collectors use either a liquid or air as their heat transfer medium. In most applications, a liquid is used and the heat is transferred to a heat storage (usually a water tank). Air collectors face the problem, that it is hard to store the exploited heat. Therefore, the heated air is usually directly fed to the interior of the building. One problem of these installations is that usually buildings do not have a large heating demand when the sun is shining. The same problem holds for liquid collectors that are directly connected to the heater. This is why the authors expect these special collector technologies to be used mostly in dedicated applications such as drying holiday homes or heating industrial buildings with different characteristics as residential buildings. For these products it is essential that the specific niche markets and their specific requirements in different climates are identified.

Heat pipes can be an interesting technology for building-integrated collectors. In heat pipe collectors the absorbed heat is transported from the absorber to the header tube by heat pipes. Therefore, the solar fluid only has to be pumped through the header tube but not through the absorber. The separation of the hydraulic circuits of the absorber and the header tube enables highly modular and flexible collector concepts, which are of great benefit for building integration. Especially the dry connection of the heat pipe to the header tube allows collector concepts leading to a high architectural flexibility in design and thermal output. With these modular collector concepts, production, installation and maintenance costs could be reduced. As the solar fluid only flows through the header tube, less pumping power is needed and the hydraulic connection of several collectors can be simplified. Heat pipes can also offer stagnation protection for the header and piping system as they can be designed to stop working (dry out limit) above a certain temperature. Above this limit the thermal resistance between absorber and manifold increases suddenly so that stagnation temperatures below 100°C in the header tube can be reached. Heat pipes have been used mainly in vacuum tube collectors with a cylindrical shape. State of the art heat pipe collectors only operate successfully with a certain minimum inclination. To achieve high design freedom and high thermal output, the reliable operation of long heat pipes under horizontal orientation must be guaranteed. The connection of the heat pipe to the header tube should be developed and optimized. The long term stability of heat pipes and the connection to the header tube should be optimized taking production cost into account. New shapes of heat pipes could provide a wide range of applications and offer a higher degree of geometrical freedom.

Solar thermal faces the competition from PV and heat pumps. One option within a decreasing market could be the combination of PV modules and solar thermal collectors. These PVT collectors need to be thermally optimised to match the requirements of PV cells and solar thermal collectors. For a successful architectural integration these new BIPVT modules should offer flexible dimensions and appearance. Industrial production could help to decrease the cost.



The identification of niche markets for special products requires an in-depth analysis that takes all building types, different collectors and different climates into account. The problem is the completeness of all the available data and correct assumptions for all cases. The development of heat pipe façade collectors can lead to advanced aesthetics, easier construction processes and lower cost. This is why the authors consider these ideas to be very important in the short-term. The same reasons for cost savings in the BIST case should also apply for BIPVT collectors. At the same time the total efficiency (including electrical yield) could be increased.

3.3 Components and materials

3.3.1 Glazing / cover

One strategy for inexpensive collector façades that are appealing is the use of specialised glazing. This should somehow hide the absorber and visible pipes inside the collector component. Today, manufacturers of collectors offer only a few different kinds of glazing (structured or clear). This makes it difficult to simply mount standard collectors on a façade. Diffusing, coloured glass has already been developed [8].

Another strategy for breaking the smooth black appearance can be macro structures. These have been designed (e.g. [38]) to have high transmission for large incidence angles, but can lead to problems with glare. While the micro structure is used for diffusion, nanostructures can be used to decrease the reflection. For all these structures, the established glare evaluation is hardly valid. Glare evaluation is discussed in section 3.7. In general, for solar energy (including PV and PVT), diffusing layers need to be evaluated taking glare into account. This becomes crucial in an urban context.

In the vertical, there are fewer times of stagnation and high temperatures than for large collector fields mounted on roofs. Nonetheless, depending on the operation mode and the application, high temperatures can occur and a sufficient insulation towards the interior of the building is required. For special ((semi-)transparent, translucent) collectors, the insulation can be provided by several layers of glazing between the interior and the absorber as described in [39]. In these cases, a reasonable combination of covers and positions for coatings must be chosen in order to provide sufficient daylighting (e.g. for offices) and a high solar transmission to the absorber. This can also depend on the position of the collector in the façade and the combination with completely transparent areas. Placing the absorber in the spandrel area of the façade can be beneficial since this part hardly contributes to daylighting. For the simulation of these systems the polarisation of the radiation can become more important. More detailed sky models could help to improve the accuracy of the simulations.

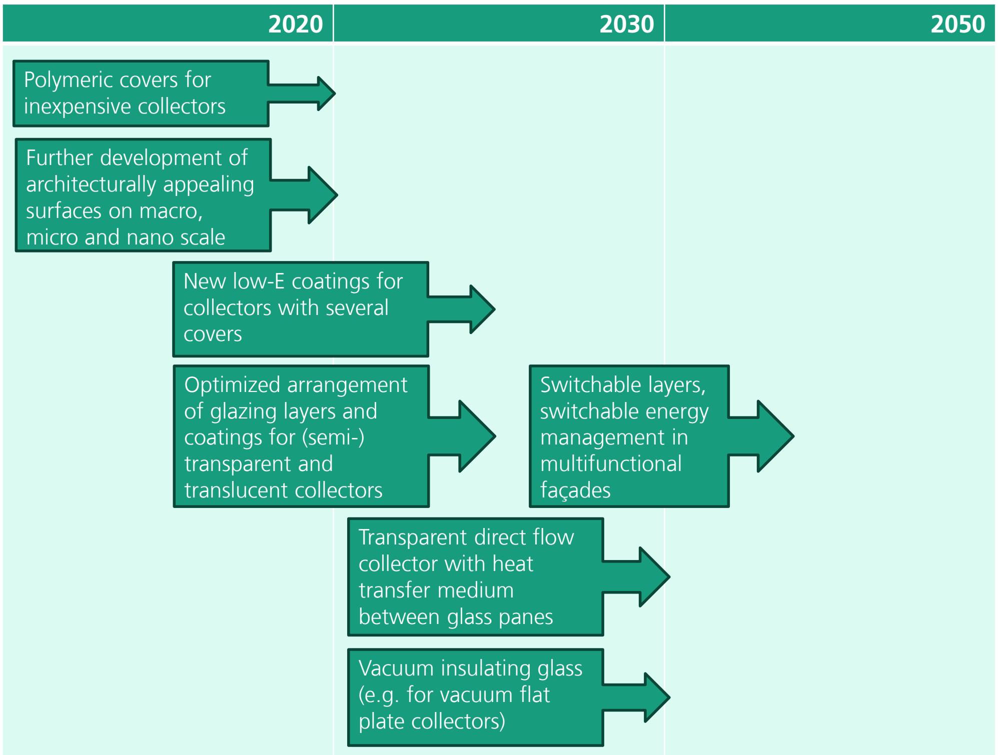
Further development of low-E coatings could provide better insulation for these collectors. These coating have a strong flank to decrease the emitted infrared radiation, but allowing visible light to be transmitted for daylighting. For the insulation between the absorber and the building interior, a higher visual transparency and a lower emissivity would be beneficial. Regarding the cover glazing, structures with a high solar transmittance and low emissivity could improve the solar thermal performance. However, coatings already reached a high state of the art and the development of better coatings can take some time.

Another option for better insulation can be improved vacuum insulating glass (VIG). The major challenge is the thermal strain. Especially for big panes the connection of the glass at the edges is the main problem. Due to very different temperatures across the both sides of the VIG the two panes expand differently. The temperature difference can get high in the BIST case during stagnation. The full potential of VIG has not completely been used yet because of this thermal strain. The efficiency of todays VIGs lies in the range of a double glazing due to suboptimal low-E coatings and/or low vacuum. The most important issue therefore is the connection of the glass panes. This must be air tight for the whole BIST lifetime. The production should allow individual dimensions while being automatised as far as possible. As soon as reliable VIGs are available, they could be developed further to a reliable and inexpensive vacuum BIST collector

Switchable layers (e.g. electrochromic or thermochromic) could allow a switchable energy management, which avoids stagnation and thus improves the correct dimensioning. These layers could also be applied in multifunctional façades to switch between (semi-) transparent and translucent properties or to switch the secondary heat gains. However, the cost of these layers must strongly be decreased to enable such technologies.

For lower collector prices, the application of polymers has been considered [40,41]. Due to the better stagnation behaviour of vertical collectors, polymeric covers become interesting. Due to their inexpensive production process, they can help reduce the price of the equipment and corresponding cost, which has been one of the major problems of ST uptake. Companies working on polymeric collectors expect their technology to be affordable in every country of the world.

For prestigious buildings, special collectors can be an interesting option. These could use glazing with a heat transfer medium in between the glass panes. In this case, different setups for the layers and the used medium must be evaluated. Using different heat transfer fluids could even result in a switchable collector. For this application the deflection of the transparent cover must be investigated since the pressure changes depending on the operation of the collector, the irradiance and the temperatures of the ambient and of the interior. The static pressure also changes with the height of the collector in the hydraulic system of the field. Tightness of this system is a crucial point as well as aesthetics.



The major issue of new covers is that existing glass has been improved and already performs quite well with transmissions of over 90 %. A striking impact of ecological and economic improvements due to better performance of the cover will be very hard to achieve by new coatings or surface structures. Switchable layers for example are still expensive. The authors expect these solutions together with special collectors (transparent, …) to be first used mainly in prestigious buildings. For VIG it is very hard to handle high temperature differences, which will be even higher for solar thermal applications. This is quite challenging. The further development of polymeric collectors can offer inexpensive and flexible production. This is why research and development should be focused on this in the next years.

3.3.2 Absorber & Hydraulics

For standard flat-plate collectors, standardised production schemes with only very few different sizes for the collector case (and usually also the absorber) have been established. Thin copper or aluminium sheets are used for the absorber. The hydraulic circuit is mostly meander or harp shaped. In automated production processes the meander tube and the absorber sheet are taken from a roll and the welding (also of the header tube) is done by a machine automatically (Figure 1). With this method, the width of the absorber is dictated by the width of the absorber sheet. With this limitation the machine shown in Figure 1 allows arbitrary geometries for the hydraulic circuit that is welded to the backside of the absorber sheet. This would even allow triangular absorbers e.g. for gable façades. Using todays machines for these collectors means more manual labour for cutting and welding or soldering the header tubes. Also the effort for logistics within the production line increases. The industrial processes used for mass production today should be rethought and improved towards individual geometries as it is already the case e.g. for windows. An alternative could be fin absorbers. Here the absorber consists of several fins mounted next to each other. These can be produced as yard goods and cut to the right length and geometry.

In [1] the authors already presented jointing options that improve aesthetic appearance of the collector. In order to obtain an even and smooth appearance of the absorber the jointing of absorber and its hydraulic circuit should be done on the back side of the absorber sheet as long as the absorber can be seen directly and is not hidden behind diffusing glazing. In case single absorbers are integrated in the building skin e.g. by a carpenter, the hydraulic connections should be simple (plug and function) and failsafe.

There are several options to improve the functionality of todays absorbers. Usually the absorber of flat plat collectors and vacuum tube collectors is coated with a highly selective layer. This allows a solar absorptance of 95 % at an emittance of 5 %. If the electric conductivity on the surface could be increased (e.g. with graphene layers), the efficiency could be further improved. The cost competitiveness must be evaluated for this rather little potential for improvement. New weatherproof colours (not only for metal surfaces as in [42]) can help improve uncovered absorbers or plaster integrated ST.

Another option for improved functionality of the absorber is to find a combination of low pressure drop and an improved heat transfer from the absorber to the heat transfer medium. Absorbers with integrated fluid channels can be interesting. The solutions shown in Figure 7 can be extruded or manufactured with two sheets and a combination of a welding technique and blow forming. These new techniques enable more dimensional freedom combined with mass production.

The absorber shown in the bottom of Figure 7 has integrated bionic structures as fluid channels. The flow of the heat transfer medium in the channels is more homogenous and the heat transfer is optimised compared to an absorber sheet with conventional pipes. These bionic designs can easily be calculated for different boundary conditions like the shape of the absorber and the location of the hydraulic connections. These different shapes of the absorber can be manufactured easier due to the different jointing technique, which is a combination of roll bonding and blow forming. These processes need to be automatised and turned into mass production. Bionic structures have been developed only for single absorbers up to now. The bionic structure has been integrated in a concrete absorber sample in the research project Tabsolar [43]. The extension of bionic structures to the rest of the collector field is discussed in section 3.3.4.

Figure 7: top: extruded absorber with integrated fluid channels [documents from SavoSolar, trade fair "IntersolarSolar2013"], middle: steel absorber [documents from Arcelor Mittal, trade fair "IntersolarSolar2013"], bottom: absorber with bionic design [44]

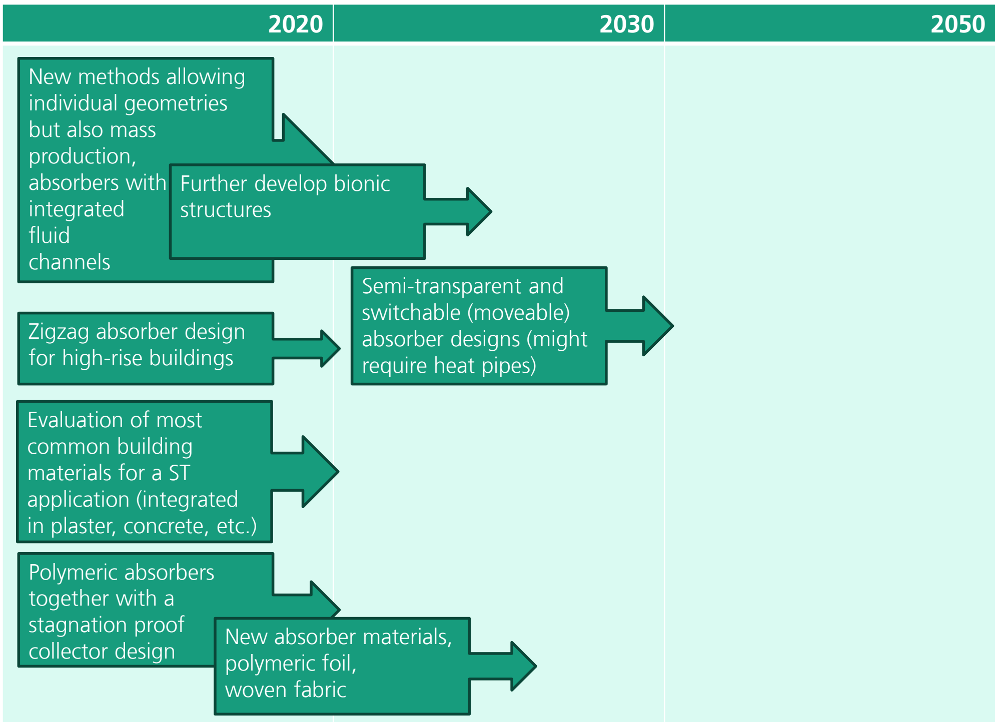
Up to now the collector has been an add-on for the building in most cases. With BIST the collector can fulfil functions of the building envelope. Another way of thinking is the question in how far the building components might fulfil collector functions. The concrete absorber from the project Tabsolar was mentioned in the previous paragraph. If one (or more) building component takes over the collector function in an inherent collector-building concept, it must absorb solar radiation and somehow support the building services with the heat. A study should investigate the potential of most commonly used materials to be activated for solar thermal. This can be accomplished with capillary tubes or bionic structures integrated in the material. With a hydraulic connection that allows fast and simple building processes, these new concept could become affordable, since regular building materials are used for the collector as far as possible. In order to improve the rather low efficiency of these solutions, a low resistance to the tubes and optimised optical properties (high solar absorptance, low emissivity and the right visual reflectance) must be given priority.

A semi-transparent collector was developed in the project Cost-Effective [45]. This can be interesting for high-rise buildings with double skin façades. The installation in the spandrel area can be a good option, since this part of a transparent façade has only a weak influence on the required artificial lighting. If the transparency was even switchable, this could help prevent stagnation and enable an energy management. A transparent façade collector could also reduce the demand of artificial heating. Switchable collectors could be constructed with mechanically movable parts. These could be built similar to venetian blinds, which can also allow full visible contact to the exterior if wanted. This would require new concepts for the heat transfer from the absorbing layer (e.g. on the surface of the venetian blinds) to the header tube (e.g. in the frame of the double skin façade). The dry connection of heat pipes as described in chapter 3.2 can be an option.

Other special collectors might use different materials like polymers in different forms like foil or woven fabric.

For polymeric absorber the same cost saving potential as for covers is expected. The problem is the stagnation temperature that is too high for inexpensive polymers. A stagnation proof collector design could solve this problem.

Another idea for improving the aesthetic impression of the absorber on opaque parts of high-rise buildings could be a zigzag design with an absorbing layer directed upwards towards the sun and a diffusing coloured layer facing the ground below the building. This requires absorbers that are produced in thin stripes and different lengths.



Since the energetic behaviour of absorbers has been optimised, the focus for the next years should be on new concepts that combine mass production and individual aesthetics. Polymeric collectors are expected to decrease the cost of collectors. Semi-transparent and switchable (probably moveable) absorbers are expected to be expensive and therefore to be established in niche markets first.

3.3.3 Concentrator optics

Some applications (e.g. solar cooling) can require higher temperatures. One strategy is to concentrate the solar radiation. Concentrating systems can either be tracked after the direction of the irradiance or be stable. Usually these solutions require a high irradiance which can be challenging on the façade during summer.

Several stationary concepts have been developed. The semi-transparent collector from Robin Sun is shown in Figure 8. Part of the radiation that has not been absorbed is reflected back from the second pane, which is located between absorber and the interior. In a research project, a semi-transparent reflector has been installed that concentrates the solar radiation on vacuum tubes (Figure 4).

Figure 8: Collector from Robin Sun that uses reflection from the second glass pane [46]

In case of larger dimensions or other geometries (e.g. for flat absorber) as shown in Figure 9 on the left, the concentrator is expected to also consume more space in the depth of the façade. Another option could be mirrors that are installed outside of a regular flat-plate collector as shown in Figure 9 on the right. In general, concentrating systems are more sensitive to the geometry of the concentrator and the direction of the irradiance (in order to really reach their high temperatures) than regular flat-plate collectors (for low or medium temperatures). For different locations and orientations of the buildings, different geometries of the reflector could be needed. Ideally, the optimum concentrator optic is calculated and manufactured individually for each application. Another way is to optimise the geometries to match multiple applications. In a first step the parameters influencing the geometries of the different collector concepts must be identified and optimised cases must be narrowed to as few standard cases as possible. Broad architectural design studies of the targeted buildings and urban districts should be conducted taking costs, feasibility and acceptance into account. The load bearing structure should also be taken into account. One idea is to use cardboard, which can easily be cut to the right geometry as the structure holding the reflector [47].

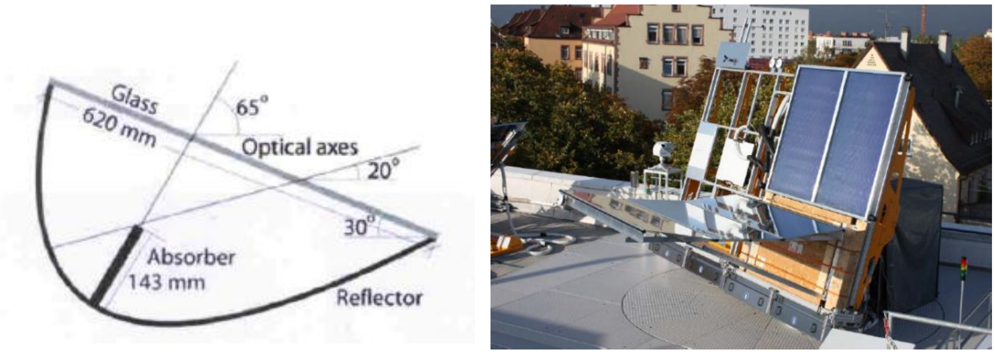
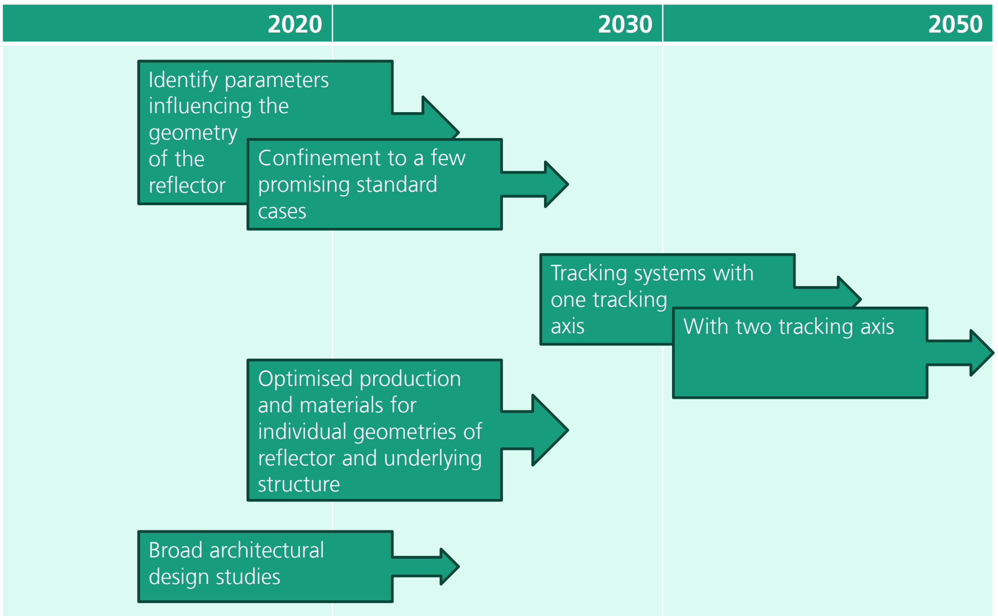


Figure 9: different concentrators, left: reflector surrounding the absorber [48], right: reflector is mounted in front of a flat-plate collector [48]

For all these concepts an evaluation of glare towards the interior and in urban contexts is very important (section 3.7).

Building-integrated tracking systems seem to be challenging. Tracking systems can follow only the profile angle or also the azimuth angle of the sun. Tracking of the profile angle only would result in parts that need to rotate e.g. around a horizontal axis. These systems could be realised with heat pipes as mentioned in sections 3.2 and 3.3.2. An increased effort and maintenance is expected. It was hard for the experts to consider façade-integrated tracking systems with two tracking axis. These should be rather understood as outlook.



Since the systems with concentrators might be used for dedicated applications with high temperatures, they are expected to be first established in niche markets. These systems require extra effort, while the radiation in the façade is limited. Therefore they are expected rather to be used in prestigious buildings. Glare must be evaluated for the façade including the exterior and the interior of the building. For lower cost, the individual geometry of the concentrators must be narrowed down or the production must be individualised with inexpensive materials while supporting industrial processes.

3.3.4 Hydraulic interconnection of collectors

For refurbishment projects with a given geometry of the façade areas, one cannot expect todays products to exactly match the façade's dimensions. One might end up with several collector arrays of different sizes at different positions of the façade. This means that it is not possible to simply connect the collectors according to the Tichelmann [49] configuration, which does not need pressure equalisation due to similar collector fields and pipe lengths. Valves will be required in order to obtain a homogenous flow in all collectors. Integrated valves in the hydraulic interconnections of the collectors (or absorbers) can be an option.

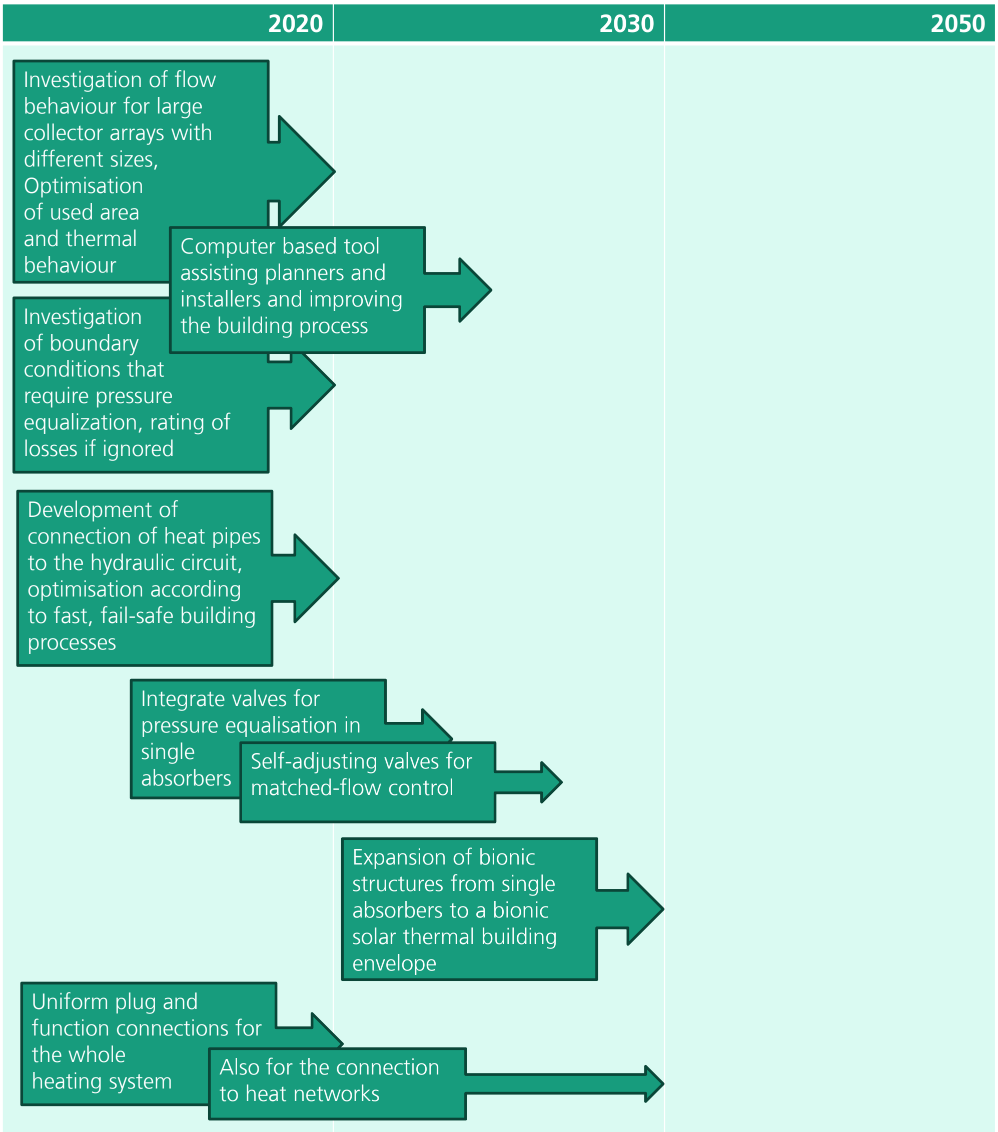
For the optimisation and automated calculation of the adjustment of these control mechanisms, further research projects are needed in order to understand flow characteristics in all (maybe customised) absorbers of the different arrays and obtain a controlled stagnation behaviour. Computer based tools are needed that have a choice of collector technology and the geometry of the façade as an input. They should optimise the usage of areas and give the pressure drops as outputs. Equally distributed flow seems to be challenging even more for collector fields with matched-flow control. In this case the outlet temperature of the collector field is supposed to be constant, which leads to different total mass flows. Maybe self-adjusting valves can be an option in the future. This requires detailed knowledge about the behaviour of every single collector within the specific hydraulic configuration.

Some solar companies claim that the equalisation of the pressure in case of smaller fields of different sizes can be neglected and that stagnation problems for U-shaped hydraulics are not a major issue. Especially in tall buildings, besides the pressure drop of the collector due to fluid dynamics, one must also consider the static pressure. A systematic investigation of the boundary conditions that require pressure equalisation and a hydraulic separation after a certain height should be conducted and the effect and their sensitivity that occurs when hydraulic issues are ignored should be rated. The construction process will be much easier and faster when the extra valves for the pressure equalisation can be omitted and do not need to be adjusted accordingly. In case the different pressure drops are ignored, one should know how big the losses compared to a perfect installation will be.
Another strategy for a fast and fail-safe installation can be plug and play (or plug and flow or function) hydraulic connections. These have already been developed for the interconnection of industrially manufactured collectors [50]. This concept should be extended for the integration into the building services.

Homogenous flow in single absorber structures has been optimised with bionic structures (Figure 7). These structures can be optimised for the actual shape of the absorber and the desired position of the inlet and outlet. Proposed research should investigate whether this concept can be transferred to a whole building skin with vast collector areas that might be distributed over the façade. Fittings like dividers, collecting manifolds and elbows should also be designed in order to minimise the auxiliary energy demand for pumps.

Usually the stagnation has an impact on the hydraulic system of the whole installation. For this issue and for an easier installation, heat pipes could be an option. Above certain temperatures all the working fluid inside the heat pipe evaporates and thus the heat transfer to the collecting manifold and the rest of the hydraulic system decreases. For collectors using heat pipes, new connections to the header tube must be developed.

Research topics



The success of large collector façades will depend upon the simplification of the installation and building process, so that labour cost can be saved. This will be supported by simple and failsafe interconnections, if possible without any valves. For this it should first be evaluated, when pressure equalisation can be neglected. The new and simple tools for architects must then be based on the new knowledge. They should not burden the architect in the first drafts of the building, but create warnings, when the architect's drafts result in unfavourable boundary conditions (e.g. high cost due to many small scattered individual collectors). The software should continuously be updated with new collector technologies.

Integrated valves in every absorber seem to increase the effort for the installation. Especially in this case, fail-safe and easy-to-use procedures are needed for the installer. Smartphones could be used for these procedures. For instance, a picture of each connection could automatically be checked for the QR-Codes of both parts. All pictures might be necessary to print a certificate like "everything was double-checked, the whole system is installed correctly". The same software family could provide a list of necessary components for the chosen system, too, and allow an easy check, if all necessary components have been delivered and installed.

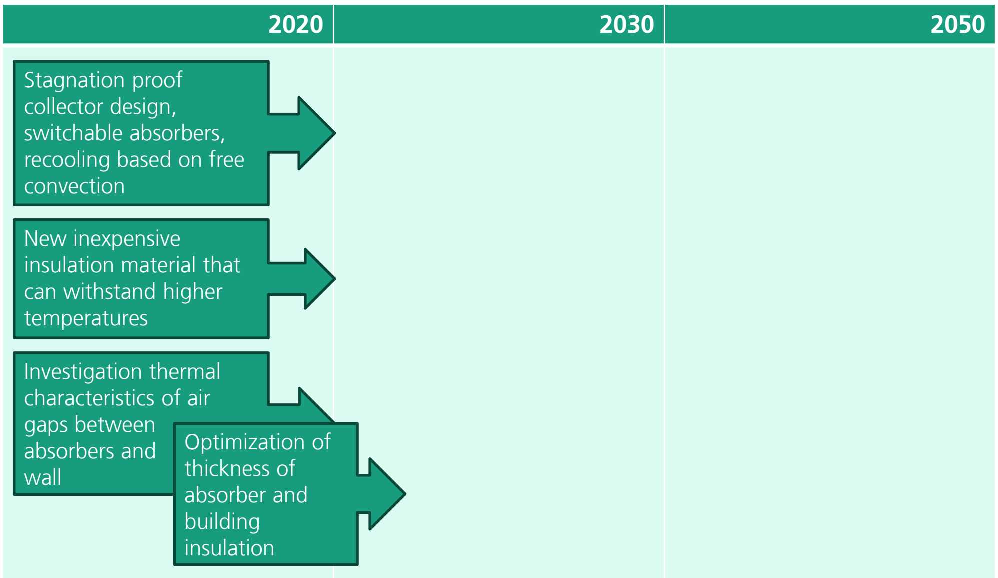
3.3.5 Insulation and building integration

For façade-integrated solar thermal concepts it was shown, that it can be beneficial to share the same insulation for the collectors and the building. Questions about the building physics of these solutions arise. The two major issues are the reached temperatures and the vapour transfer. Vapour transfer is discussed in the next chapter.

In order to decrease the heating demand of buildings many exterior insulation finishing system (EIFS) are installed on opaque building skins. Inexpensive materials are used that could not withstand the high temperatures of a flat-plate absorber during stagnation. New inexpensive high-temperature insulation materials would help here. The mounting of the absorber and the glazing needs to avoid thermal bridges. Another option is to improve the collector design toward a stagnation proof collector that does not reach high temperatures during energy cuts or when the heat store is completely filled. One option could be switchable collectors. This could be realised with moveable absorbers, which are "hidden" behind opaque areas and dragged in the aperture area with flow resistances only when there is mass flow. Another option can be recooling mechanisms, which do not depend on electricity but rather on free convection. As soon as stagnation proof collectors are established, inexpensive materials can be used for almost all parts of the collector, the surrounding building elements and the integration into the building services.

The authors found in [2] that due to unanswered issues related to building physics, most of the building companies would rather install façade collectors with a back cover and an air gap between back cover and the insulation of the wall instead of integrated absorbers. There are many unanswered questions when it comes to ventilated air gaps behind the collector. In order to calculate the heating demand of the building, it is important to know the U-value of the wall. In the building sector, this value is well established as a measure of the thermal behaviour of a wall structure. In the BIST case, this thermal behaviour can vary due to different configurations of the collector and the façade. Even more, the efficient U-value varies with the temperature of the absorber, which depends on the irradiance and the operation mode. For the thermal modelling of the façade it is important to know the heat transfer coefficients between the air gap and the surfaces. These are well known for box-shaped closed cavities. Many BIST installations exceed these limitations. There are e.g. various options for the design of the edges of these cavities. They could be closed or (partly) open as for todays roof mounted collectors. Not only the edge but also the supporting structure of the collector layer can influence the convection behaviour in the air gap. The convection depends on the geometry of the air gap, the temperatures and the wind conditions. In order to obtain accurate numbers for the air temperature in the gap, and the heat transfer coefficients, detailed CFD simulations and measurements will be needed. These studies will lead to new models that can be used also for other active multifunctional façades e.g. with (BI)PV(T). A rather simple way to install a PVT façade is to mount regular PV modules with an air gap at the rear. The heated air from the air gap could then be used for the building services. A detailed knowledge about the effects of air gaps on the building physics (including vapour transport) can help to optimise the thickness of the building's and the collector's insulation. For these air gaps also issues related to fire safety will need to be discussed (see section 3.7).

Research topics



One of the main challenges is the cost of ST. In [2] the cost saving potential of BIST was shown. As soon as the remaining doubts about buildings physics haven been answered for most possible applications, this potential can be used. Even more savings are possible with inexpensive materials that can be used in combination with stagnation proof collector designs. This is why all the topics of this section are considered to be important for the next years.

3.3.6 Vapour barriers and vapour transfer

There are two issues related to vapour transfer. The first one is the removal of moisture from the interior of the building. This is expected to be negligible, since new and refurbished buildings are supposed to be air tight, which requires the technical building equipment to handle this problem. The other point is that damages due to condensation within the façade must not occur. This is more critical in northern climates and during winter, when the interior is heated while the exterior is exposed to the cold temperatures. Relative humidity close to 100 % should be avoided. At least it should be avoided for long periods, so that the wall can dry out, if condensation occurs in extreme cases. For this problem there are two strategies. One option is to use vapour barriers in order not to allow too much vapour to enter the wall. The other option is a construction that is more and more vapour-open towards the exterior in order to let the vapour exit the wall according to the direction of vapour diffusion. When building-integrated collectors are installed, the (flat-plate) absorber or the glazing is typically a vapour barrier which allows no vapour transfer (if the absorber is not perforated). Vapour condensations at surfaces of the absorber or the glazing that are directed toward the interior of the building could be possible. This would lead to wet insulation materials and building damages. A benefit of BIST systems is that the absorber reaches high temperatures frequently. This can evaporate the moisture but leads to a second problem. The high temperatures of the absorber lead to an inversion of the temperature gradient within the wall. The gradient of relative humidity changes and the vapour must exit the wall towards the interior of the building. Therefore the diffusion resistances between absorber and interior of the building may not be too high. This behaviour has been investigated for 5 rather different constructions with BIST in [16]. The calculations and the measurements of two demo façades did not reveal critical condensations. Nonetheless, these issues should be evaluated for different wall constructions and climates in order to give answers to the concerns of construction companies and architects. New materials such as humidity-dependent vapour barriers should also be considered.

Research topics

2020	2030	2050
Investigation of vapour transfer for most common wall structures and different climates, take new materials such as humidity-dependent vapour barriers into account		

The investigation of building physics can help to make decisions for BIST in the planning process easier, increase the cost-benefit ratio of installations and contribute to issues related to warranty. This is considered important for the near future in order to stimulate a broader market uptake.

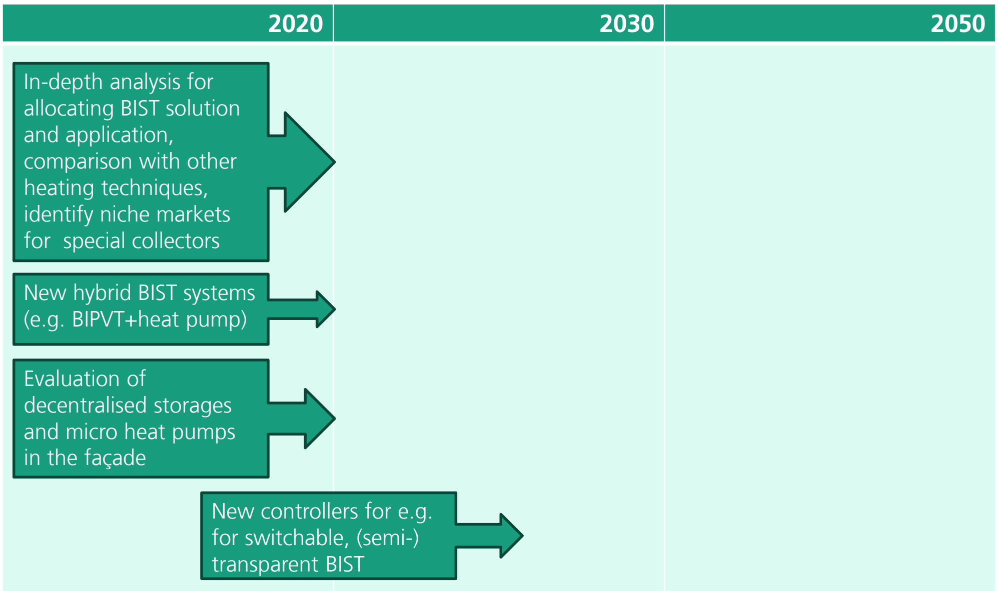
3.4 Systems engineering

The performance of a solar thermal system strongly depends on the specific application and the control strategy. In extreme cases, when for example collectors of medium efficiency are supposed to only support solar cooling, they might fail, if they reach the required temperatures only for very short times distributed over the year. An in-depth analysis matching BIST solution to most promising applications has already been proposed in section 3.2.

New technologies for the connections required in advanced heat networks with different temperature levels (maybe even cold networks) are an outlook beyond the scope of this roadmap.

One strategy to stimulate the market uptake of solar thermal façades could be new hybrid systems. These could consist of combinations with PV, heat pumps or even both. Also the regeneration of ice and ground storages can be considered. This could require low temperatures leading to higher collector efficiencies. These systems must be investigated for different buildings with different heat demands and different degrees of centralised systems. Integrating parts of the building services into the façade could reduce the necessary work inside the building and offer new options for solar thermal, too. Decentralised storages or decentralised micro heat pumps also integrated in the façade could be an option. Financial government incentives might dictate certain solar fractions e.g. for SolarActiveHouses. In general it is important to have a clear understanding of this quantity. A bad example would be a system with a huge collector gain, but a poorly isolated tank, which leads to large auxiliary energy demand. If only the collector gain and the heat demand are compared, one might end up with a high solar fraction, while hardly any auxiliary energy is saved. For hybrid systems it is even more important to find suitable system boundaries which allow meaningful quantities to easily measure the environmental quality of the application. For (semi-)transparent collectors, the new system boundaries might also consider passive heat gains and demand for artificial lighting.

Special BIST systems (semi-transparent, switchable) might require new controllers, which take all requirements of the building and its tenants (daylighting, view) into account.



Research topics

In order to stimulate the market in the short-term, it is important to find the most promising match of application and BIST system. Renewable building-integrated hybrid systems can help to combine the benefits of BIST and maybe even several other renewable technologies, which have stronger market shares. New controllers must be established in the medium-term for special collectors as the authors expect them to become commercial products between 2020 and 2030.

3.5 Prefabrication

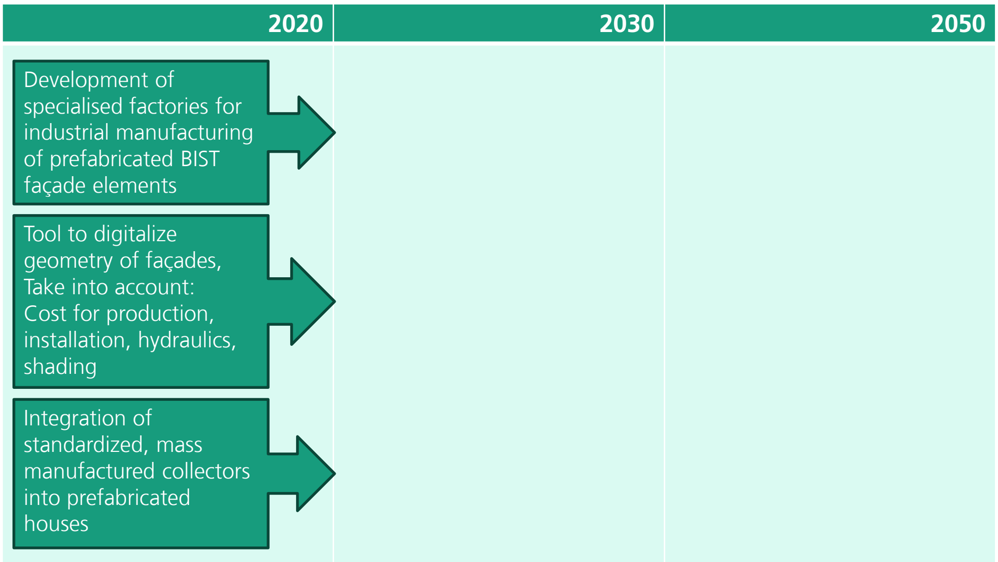
In order to reduce the cost, prefabricated façades or façade elements are a promising option. The main advantages are a quick installation and shorter times of disturbance for the residents or users inside the building. In a specialised factory, multifunctional façade elements can be built with less faults and lower cost than outdoor on the building site. The authors expect this concept to be especially successful for districts with similar buildings e.g. the prefabricated concrete buildings from the 1960s.

For the refurbishment of these buildings, it is important to develop inexpensive tools to digitalize the building geometry with good accuracy and optimise the fragmentation of the façade area into prefabricated modules. This must take the production and installation costs as well as hydraulics and shading into account. Without these tools, the optimisation will be more difficult for refurbishment.

An integration of solar thermal collectors into new prefabricated houses would be very beneficial. The authors showed that customised building-integrated collectors can be less expensive than standard collectors. The integration into the building skin could be as simple as for regular windows and pipes for the houses. These prefabricated houses are standardised to a degree that they can be chosen from a catalogue, but also modified and adapted to individual requirements. A higher degree of standardisation for these fabricated houses means that also todays mass-manufactured standard absorbers with given symmetries could be used.

In the case of new standardised prefabricated houses, the building physics of the innovative wall structure will need to be calculated just once, while for refurbishment, all wall structures will need an evaluation (cp. chapter 3.3.6).

Research topics



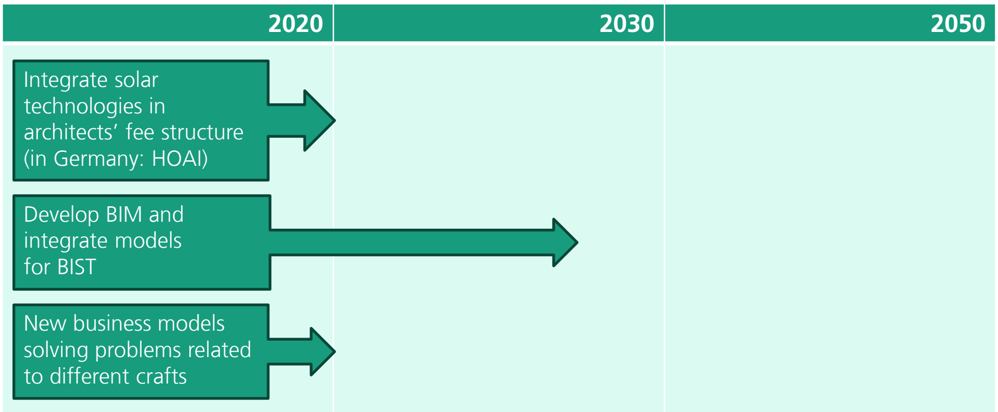
The possible cost savings for prefabricated BIST façade elements are considered high, because of the large building stock which needs refurbishment.
The potential of prefabricated solar thermal façades should be initially demonstrated. Prefabricated nearly-zero energy houses could be one of the first commercial applications of façade-integrated solar thermal. After that mass-produced solutions and the simulation tools should be developed in the coming years together.

3.6 Building process

For non-residential buildings, the construction process can become very complex. For a successful integration of solar technologies, they must already be considered in an early stage of planning. In order to make this more attractive and easier, renewable technologies should be included in the fee structure for architects and engineers (in Germany: HOAI).

The success of solar technologies in specialised buildings like high-rise buildings, it is important to first analyse the construction process itself, which can lie beyond the scope of the regular fee structure. Especially for commercial buildings, building information modelling (BIM) is required. Therefore BIST models need to be integrated seamlessly into the building models also in order to contribute to later error detection during the construction process.

The authors expected the separation of different crafts involved in the construction of solar thermal facades to be a major problem. The main problem seems to be the warranty (see sections 3.7 and 3.9). Most professionals asked for the authors' study in [2] claimed to be able to handle the technical barriers to BIST. They claimed to be able to solve the problems arising with the cooperation of different crafts.



Research topics

An integration of solar technologies into architects' and builders' regular processes must be established as fast as possible in order to achieve higher market penetration of building-integrated solar systems. Since the building sector tends to act rather conservative, the authors expect that new concepts for the construction process will only be implemented and widely accepted by 2030. In order to achieve large areas of installed solar façades, new business models can be required.

3.7 Legal issues and certification

The authors' expected the separation of crafts to be a major problem. Most professionals who were asked for the authors' study in [2] claimed to be able to handle the technical barriers to BIST. Companies in the building sector act rather conservatively. On the one hand this is due to a lack of education. On the other hand craftsmen are simply not willing to work with unknown materials. Plasterers have learned to handle exterior insulation finishing systems, but consider active technologies to be not part of their field. The same holds for plumbers in reverse. Even more so, warranty issues cannot be neglected. For systems, that use liquids as a heat transfer medium with an integrated absorber in the wall system, the companies fear expensive recourse claims. An analysis and comparison with the well-established TABS (floor heating) could be helpful. The systems need to be failsafe and need to have long lifetimes. The concerns of construction companies and other craftsmen towards these systems may be reduced by more demonstrations of varied solar façades using different technologies. The demonstrations could also help to establish yield guarantees, which are already common in the PV sector. Eventually the issue must be solved. Either one company provides the warranty or it is spread over all involved crafts. This question could be answered along with the development of new business models (section 3.9).

Issues related to contracting are discussed in chapter 3.9.

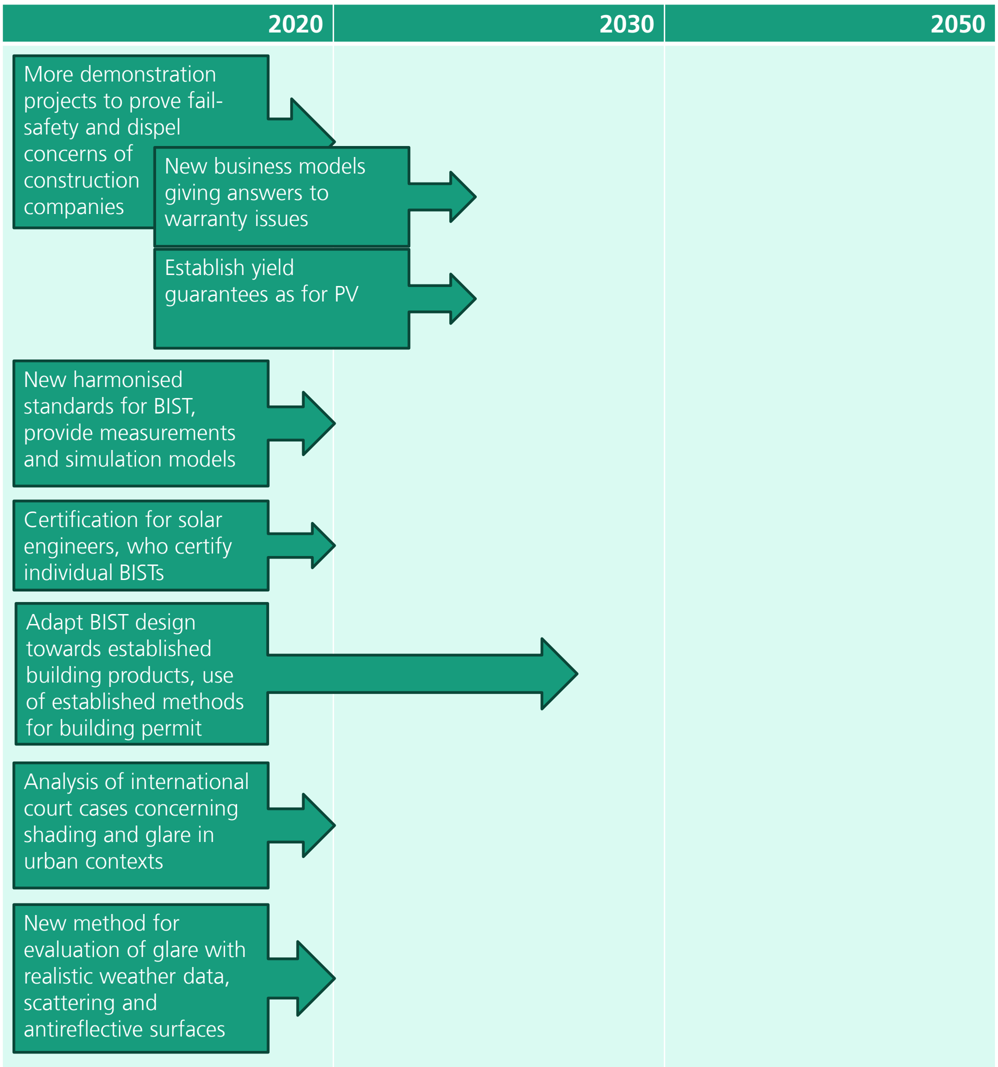
Another problem is that the methodology of the current standards cannot be transferred to façade-integrated collectors. One crucial point is that in the proposed measurements the standard collectors are surrounded by air at ambient temperature. This does not hold for solar façades that face ambient temperatures at the front and the interior building temperatures at the rear. The back insulation of a building-integrated collector can be much higher than for a building-added collector which leads to a higher collector performance. BIST collectors typically decrease the heating demand and increase the cooling demand. Due to the process of harmonisation of standards, which means that all products must be considered as building products, new standards will be required that can be applied to all the different technologies of solar thermal façade collectors, maybe covering even more façade-integrated building services. Fast simulation models have been developed to calculate the energy flux to the building interior depending on the ambient conditions and on the collector operation. A new standard could list the requirements which a simulation model has to fulfil in order to reach certain accuracies and to receive subsidies for nearly-zero-energy buildings.

Standardisation and certification (such as Solar Keymark) are required by public support schemes. To account for very innovative BIST components, certified solar engineers could use defined methods for yield predictions. These specialised engineers could easily become part of the building team as described in section 3.9.

Another option besides new standards for BIST products to match the requirements of building permits is the adaption of the BIST design towards that of already established products e.g. like the glazing of windows. In this case already established methods for the proof e.g. of fire safety might be used.

In urban contexts, when (large, high) buildings stand close to each other, two further problems can occur. The first problem is that an already existing solar plant (also PV) is shaded by a newly constructed neighbouring building. In the wider context the issue can be addressed as the right for sunlight. The other problem is that the solar plant might cause unacceptable glare on neighbouring grounds. For both problems a study of international laws and court cases could help to write guidelines and avoid expensive case-by-case decisions.

For the evaluation of glare a second problem arises. The established glare evaluation is hardly valid. It considers only flat, non-scattering surfaces and daylight with the possible direct irradiation. Newly developed methods need to take realistic weather data (no clear sky throughout the year) and the surface properties into account. Scattering or antireflective characteristics of the surfaces can lead to under- or overestimation in the established glare evaluation.



Legal issues can be a strong barrier for construction companies. In Germany the biggest concern connected to this topic is the building permit that is needed for collectors that are mounted with tilt angles above 75 ° or that have collector areas larger than 3 m^2 [24]. Public support can rely on certificates which are not valid for recent BIST systems. Therefore new standards and certificates or new support schemes can help to reduce the cost of BIST installations. These issues should be part of one or more research projects up to 2020.

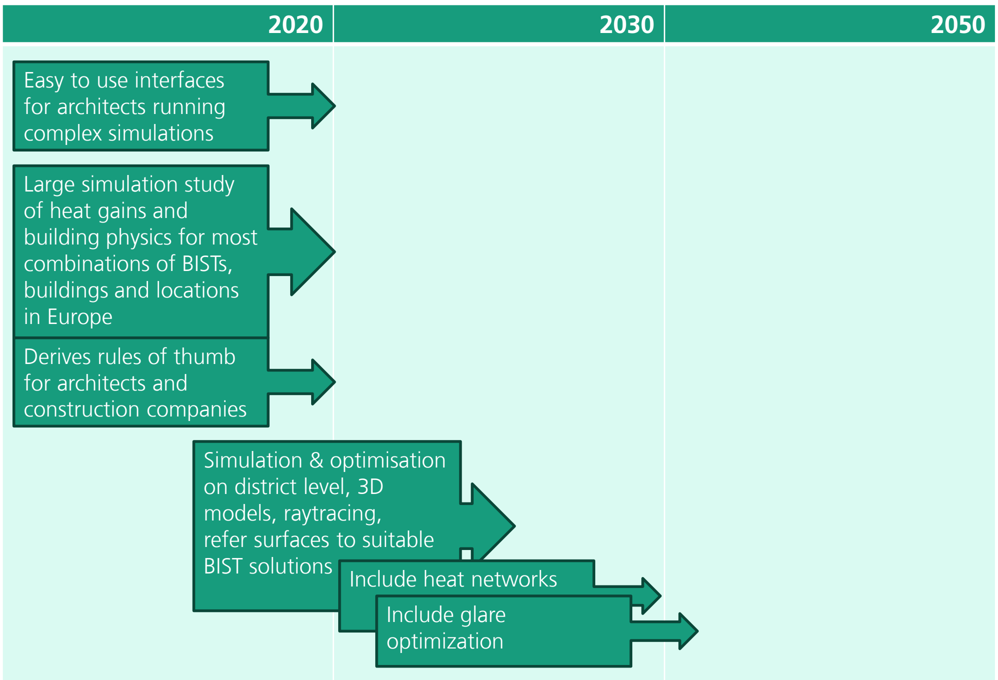
3.8 Software and simulations

The major questions are the energy output of the collector and the influence on the energy needs of the whole building. Software simulating building-added systems with standard components is available today. Building-integrated collectors and most of all the special collectors (e.g. semi-transparent) have been simulated only in scientific research. Usually, programming individual models is required for such components. These models should consider the active collector gain but also the energy flux between the collector and the building interior. For easier handling in the software for e.g. architects, these models don’t need to be replaced by simplified models that use only a few parameters. Instead, complex models with easy-to-use interfaces can be used as long as the runtime of the models is short enough.

The simulations should also give answers to questions related to building physics. These questions should be answered in a large simulation study taking all available technologies and all European wall structures and climates into account. The results need to be disseminated in a way that the experts can use rules of thumb even without running a simulation tool.

For integrated absorbers and more complex collectors (e.g. switchable ones), several standard cases should be simulated and published in order to give architects an initial impression of the energy that can be saved in these cases. Gross numbers for annual collector gains and the influence on the heating demand should be derived from detailed models in order to make first estimations in the planning process as easy as possible for stakeholders who do not have a lot of solar experience yet. These could be specific values for the dimensioning of collector and tank. An example would be the collector area and tank volume that are today calculated for DHW systems according to the number of tenants. They need to be calculated for different building integration options, while shading should also be taken into account. Another option would be to standardize the systems to a degree like todays gas condensing burners that are offered in a few sizes only (e.g. 3 different sizes for small, medium and large houses).

For future development of solar heated districts, it will be important to carry out detailed calculations. These could contain methods like satellite imagery or LiDAR (Light detection and ranging) recorded from airplanes [51], if 3D models of the district do not exist yet. The methods for the calculation of the potential of single areas will be more accurate if they contain ray tracing as described in [29] for PV. Taking the albedo of the surrounding surfaces into account can be crucial for light directing or concentrating collectors. This will reveal which areas can be used for which technology. For this, one must also consider the buildings and their specific heat demand and the influence on this from the BIST collector. If the cost of the district's energy system shall be optimised, one must take the cost of different BIST solution for all suitable building surfaces into account. A next step will be to include heat networks and their optimisation in respect of sizing and positioning (centralised / decentralised) of storages for different temperature levels and the times when the heat network can be shut down in summer. In a last step even an optimisation of glare for all relevant areas could be implemented.



Since a lack of knowledge among planners was determined to be one of the most important barriers to BIST systems [2], the gross numbers and guidelines must be derived from the simulation studies as soon as possible. The simulations on city level must be implemented in the process towards (mostly) renewable energy systems as described in [36,37].

3.9 Business structure

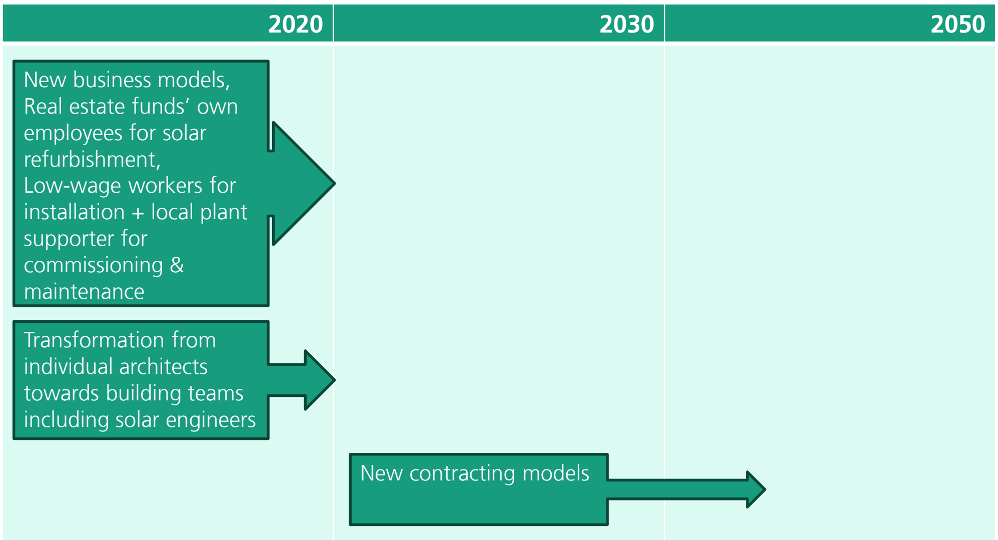
Since solar thermal façades cover the fields of many different craftsmen, it will be necessary to either assign solar façades to one craft or to establish new business models. First of all the target market should be analysed accurately for every technology. Here just some first ideas of future developments can be given. For the building stock that is held by estate funds or housing societies it can be beneficial if the company employs their own craftsmen supervised by one specially trained person. Chapter 3.5 already describes the benefits of prefabricated large façade modules with integrated collectors for refurbishment or new buildings. A further option is the combination of low-wage workers and local plant supervisor. This business model is based on a big stock of similar buildings, on which labourers install large areas of standardised collectors. The local specially trained solar thermal plant supervisor will be responsible for the integration into the existing building services, commissioning and maintenance. All these new models should be evaluated taking into account that today a major part of the prizes is due to the three-stage distribution chain (manufacturer, wholesales dealer, installer). The risk that installers tend to sell building equipment that is oversized due to higher prizes (leading to bigger discounts), could be overcome with these new business structures as well.

In the development of new components one should include work packages considering the distribution channels already in early stages of the project.

Large companies that offer solar thermal collectors also offer other heating systems. This means that solar thermal might face competition even within the manufacturing company. Usually the three-staged distribution applies for all their heating equipment. The proposed business models in this document include cost reduction due to other distribution channels without wholesale dealers. Skipping the wholesales dealer might jeopardize the contracts related to other heating devices. The interviews with professionals revealed, that large manufacturers are very sensitive to this topic.

The integration of solar techniques in architects' daily routine has already been discussed in section 3.6. An expansion of the architects' usual business model towards a building team including a "solar planner" could further promote this idea.

Contracting is considered to be a solution for the crisis that the companies experienced during the last few years. The owners of the building stock and companies tend to act conservatively, which is a strong barrier to this business model. The real estate owners fear that selling processes are inhibited if there are contracts to be fulfilled. Usually the companies providing the energy (the contractors) want to protect the ownership of their solar plant in case the building owner changes or has to declare insolvency. One option is to specify this in the contract. Then the new real estate owner is forced into the old contracts. If that is neglected, costly lawsuits or higher prizes to cover this risk could be the consequence. A safer way to protect the ownership is to register this in the land register (in Germany: "Grunddienstbarkeit im Grundbuch"). This option is expected to cause even more problems when selling the building. Answers to this problem are even more important for building-integrated systems that cannot easily be removed from the building. Break-through ideas in this field could be developed and published within research projects.



New business models can help to overcome the classic three-staged distribution system in order to reduce the cost, which is a major issue for solar thermal in general. Therefore these new business models should be evaluated quickly. Contracting models will only become interesting when large BIST projects have been successfully realised.

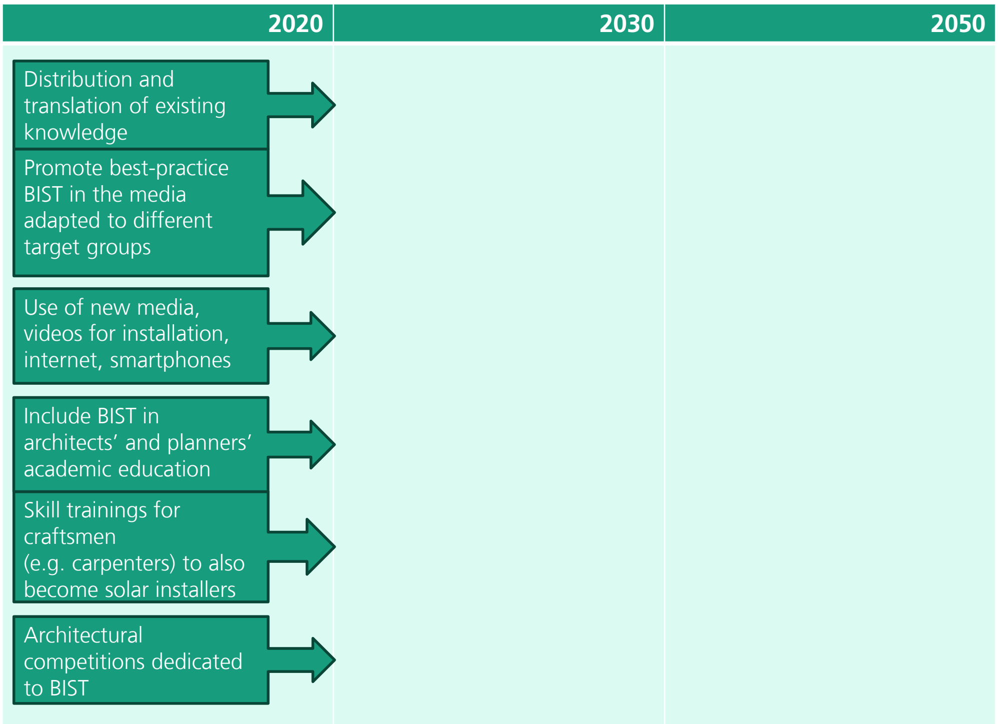
3.10 Education & training

Solar energy is only a small part of the education of architects and craftsmen. In general, the whole construction sector acts very conservatively while solar technologies are sometimes not considered affordable. For façades, more best-practice examples need to be collected and promoted in the media for all the professionals as well as for the owners of the building stock. The knowledge must be collected and presented in a suitable format for the different target groups. A lot of work in the field of building-integrated solar systems has been done in IEA SHC task 41 [52]. This will need further distribution and editing for the relevant groups and translation into more languages. The education should include not only different technologies but also give first ideas, which systems can be used for which kind of building with which size of collector field and its orientation.

Architectural competitions are a frequently used measure to find optimised solutions for dedicated building tasks. These could help to find appealing and functional BIST solutions in order to raise awareness and establish BIST among architects and in the construction industry.

For craftsmen, a skill enhancement towards a "solar installer" will be necessary in order to convince e.g. carpenters to mount and connect absorbers in their timber frame constructions.

For developing countries, explanations of the installation of building-integrated solar thermal in videos can be an option. For building owners, who decide to build their own solar plant, these videos can be a good support tool. The business model with local plant supervisors will be required for these setups.



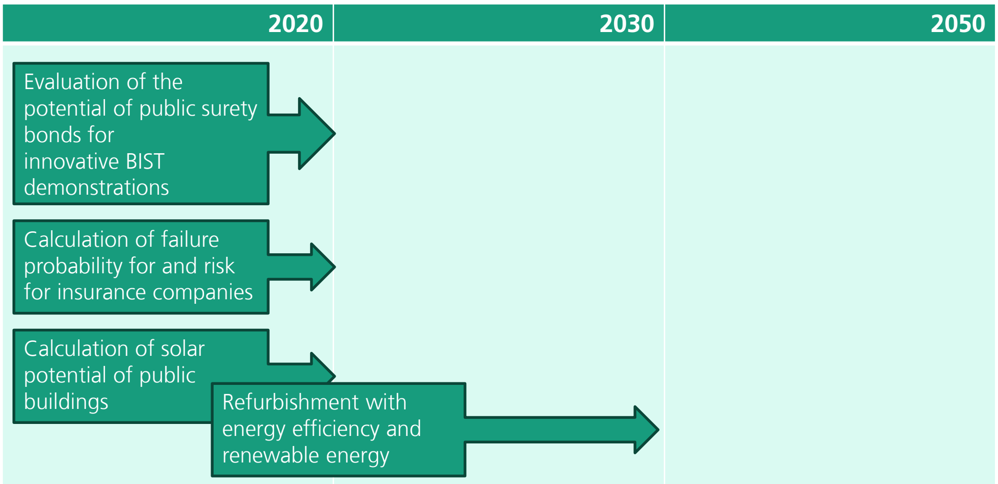
Research topics

All the measures presented in this chapter have a high potential to raise awareness for BIST. The challenge is to find the right measures to improve the education of as many stakeholders as possible. As soon as BIST is established in the architects' and the building sector's routine, more installations will be appealing compared to todays standard solution with roof-mounted, building attached collectors. Compared to the development of new products, these measures can be realised with little budget.

3.11 Political decisions and accompanying actions

For regular building products e.g. curtain façades it is possible to conclude an insurance contract. The main specifications that insurance companies need for their calculations are the values of possible damages and the probability of these damages. Unfortunately these numbers are not known for innovative collector façades. From interviews, some experts claimed that public support for insuring innovative products could help in testing new technologies on buildings under real conditions and thus proving the feasibility of these concepts. The potential of e.g. public surety bonds should first be estimated in a small research project. Regarding the risk, research projects to quantify the risk of the first commercial installations are necessary.

It is claimed that for the solar sector it would be very beneficial if the public building stock (managed by the governments) would be obliged to demonstrate new developments. This would even stimulate more innovative systems because of the non-residential character of most buildings. The huge amount of buildings could keep the companies occupied for a long time, whilst developing prototypes towards inexpensive mass-produced products for a bigger market.



Research topics

Research projects should analyse the effect of the proposed measures before the measures are implemented politically. The proposed measures could face strong opposition from the lobby organisations from the fossil and nuclear energy industry. Nonetheless they could be accomplished in limited time. The refurbishment of the public building stock is expected to consume more time.

3.12 Economic scenarios

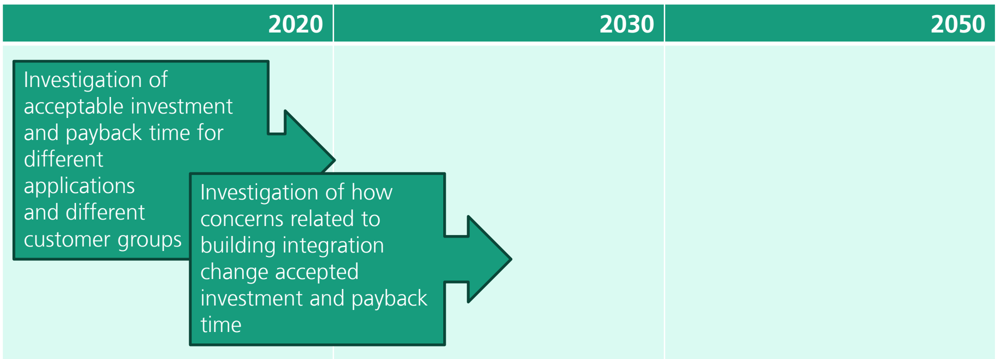
Cost is a very important factor for the decisions made for most buildings. PV has experienced a strong decrease in the module prizes during the last years [26]. At the same time the feed-in tariff has decreased. For new single family homes PV + heat pump is the strongest competition for solar thermal installations. The economic success of this system strongly depends on the boundary conditions e.g. energy prizes. For real estate holders, manufacturers and building companies as well as for political decision makers it is important to know the boundary conditions and which technology is beneficial in which scenario for which application. In order to be able to answer these questions, the investment cost and the total cost of ownership (TCO or life-cycle cost LCC) must be calculated for the different systems with their specific applications. The analysis will also require a simulation study. This and an expansion to trans-regional energy systems have been proposed in section 3.8.

Another interesting research topic could be the real estate prices of net-zero energy buildings compared to passive houses and conventional buildings as well as the value of buildings with highly aesthetic façade collectors compared to buildings with building-added façade collectors.

3.13 Psychological and sociological factors

In this field several questions about the selling process and the perception of renewables by the public arise. After 2020, new buildings will have to provide an almost neutral energy balance. This means that renewable technologies must be installed at the building or nearby. Here the offers that construction companies make can already strongly influence the owners of the buildings. For an optimisation of the systems it is very important to understand the targets. This means that it should be investigated which target groups accept which costs and how long the payback times may become. This is expected to be very different for different applications e.g. single family houses or commercial buildings held by investment companies. For integrated absorbers, companies and house owners are concerned about safety and the availability of replacement. For the manufacturers it is an important question how this influences acceptable investments and payback times and how to reassure the craftsmen and their customers. This is even more important for very innovative façade collectors.

In general, renewables are scrutinised in greater detail in the public eye than conventional energy sources. The idea is that investing in renewables should pay off as quickly as possible or that people want to earn money e.g. with their PV plant. This view is much less dominant in the decision about a new car. For the whole sector it is important to know which the most striking points are and how stakeholders can influence these opinions. It would also be interesting to know how customers' opinions and decisions could be influenced by CO_2-taxes.



Since the European market has been decreasing during the last years, it is crucial to know the boundary conditions that research and development must aim for. Therefore the topics of this section are very urgent.

4 Lessons learned & research recommendations

In past projects, the authors faced several problems that should be overcome in future research and development projects. For product developments it is already in an early stage required to have a multidisciplinary team. Architects should at least be consulted since the product has to match their needs. Engineers have a quite different background. They need to be made aware of the fact that it is not only the technical quality of a system that grants for its success on the market. In IEA SHC Task 41 the architectural characteristics of building integration have been investigated. Taking into account the outcome of their studies about the architects' preferences and guidelines for product development [52], one will end up with appealing products.

In the working plan for development projects one should include additional steps that deal with the optimisation of the building process. A good project thinks about all stakeholders involved in the building process and if all of them have everything they need. In order to get a good idea of the market and the working process of craftsmen, one should include the relevant craftsmen or their associations. These could be building engineers, plumbers, carpenters, planners, roofers, structural designers and many more.

At least at the start of development projects one must consider the needs of the market and other competing technologies. Considering at least first ideas of future business models in early stages will help to penetrate the market with innovative ideas.

5 Conclusions

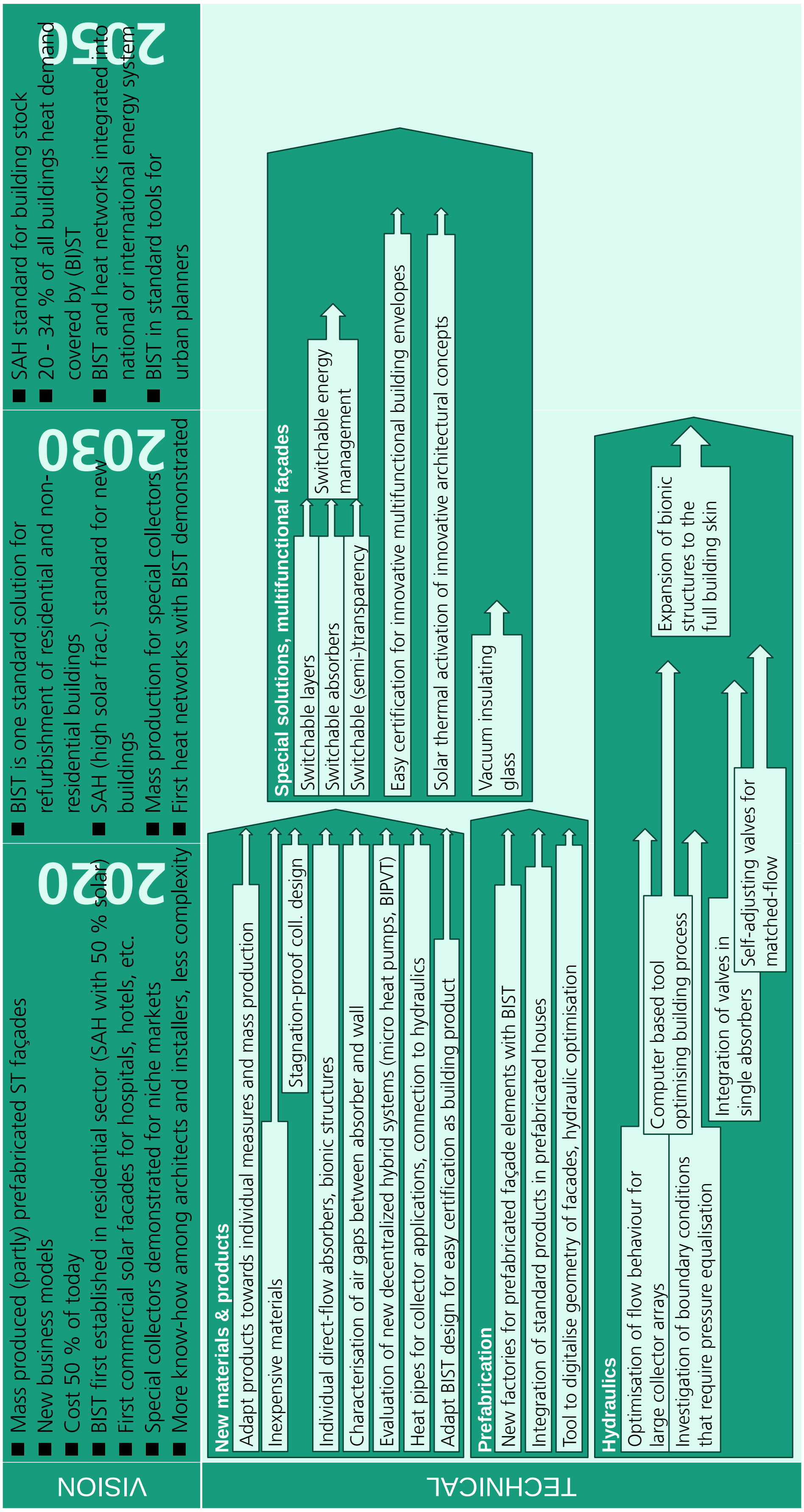
This roadmap presents a vision about future developments and which research topics are recommended in order to reach those aims.

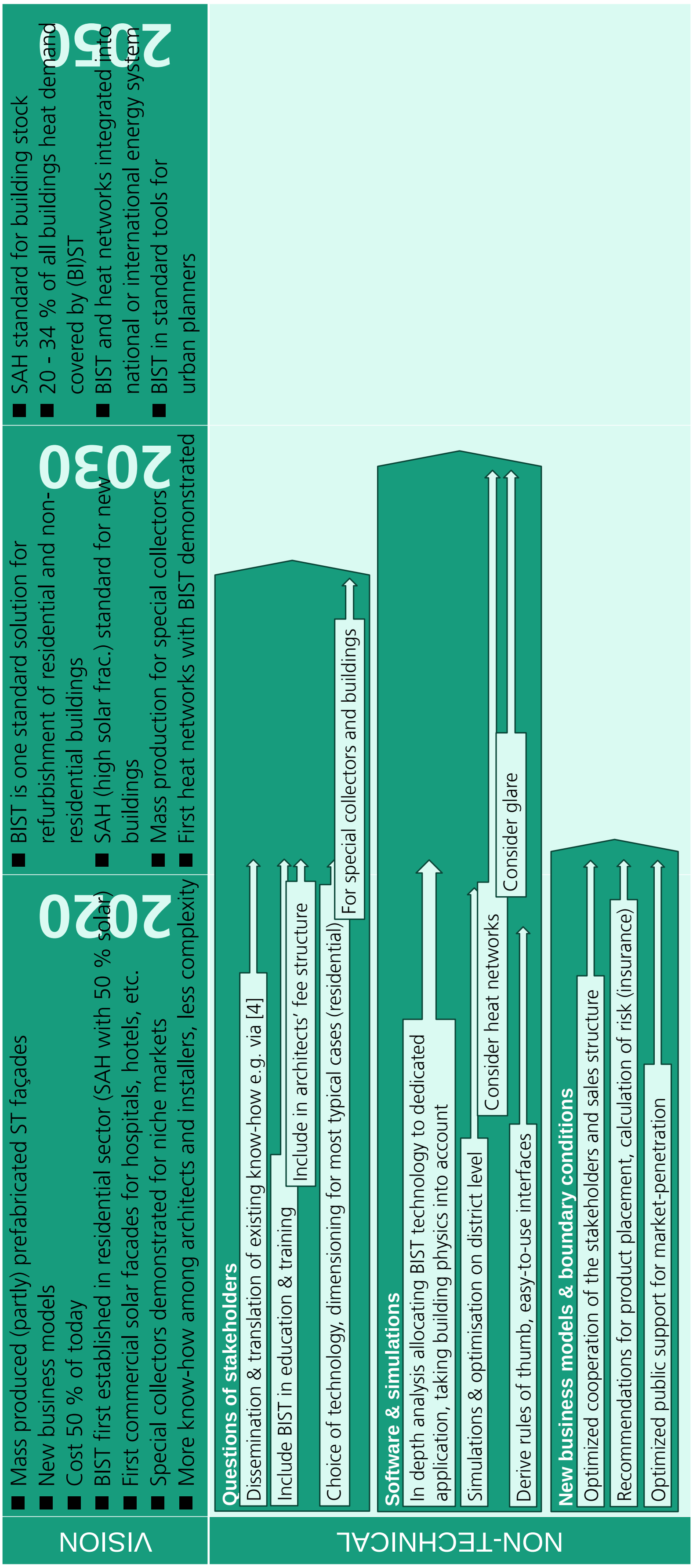
The most important topics are projects dedicated to effective dissemination and education for builders and architects. The target is to convince them and also planners of the benefits of façade-integrated solar thermal systems. At the same time, the most suited public incentives should stimulate the market. It is urgent to answer the open questions of architects and planners. These address the technology to be used and how to dimension the systems in an early stage of planning. The answers could be given by analysing different variants of real building projects taking also costs and building physics into account. With such in-depth analysed successful examples, remaining fears and scepticism also towards innovative systems can be reduced.

The second most important point is to develop further absorbers or collectors that have a long lifetime, an easy and failsafe installation and appealing aesthetics, while being manufactured industrially. The highest potential of reducing the prizes of these collector façades is to develop new business models that omit the traditional three-stage distribution. These measures are required for the mass market.

At the same time special solutions should also be developed in order to penetrate wider markets from their respective niches. In general, the authors expect holistic approaches, which take several points issued in the roadmap with an interdisciplinary team into account, to have the most success.

The graphics showing the research and development topics for the single parameters, which were shown in the previous chapters, are combined in the following diagrams.


VISION
2020
Mass produced (partly) prefabricated ST façades
New business models
Cost 50 % of today
BIST first established in residential sector (SAH with 50 % solar)
First commercial solar facades for hospitals, hotels, etc.
Special collectors demonstrated for niche markets
More know-how among architects and installers, less complexity
2030
BIST is one standard solution for refurbishment of residential and non-residential buildings
SAH (high solar frac.) standard for new buildings
Mass production for special collectors
First heat networks with BIST demonstrated
2050
SAH standard for building stock
20 - 34 % of all buildings heat demand covered by (BI)ST
BIST and heat networks integrated into national or international energy system
BIST in standard tools for urban planners
TECHNICAL
New materials & products
Adapt products towards individual measures and mass production
Inexpensive materials
Stagnation-proof coll. design
Individual direct-flow absorbers, bionic structures
Characterisation of air gaps between absorber and wall
Evaluation of new decentralized hybrid systems (micro heat pumps, BIPVT)
Heat pipes for collector applications, connection to hydraulics
Adapt BIST design for easy certification as building product
Prefabrication
New factories for prefabricated façade elements with BIST
Integration of standard products in prefabricated houses
Tool to digitalise geometry of facades, hydraulic optimisation
Hydraulics
Optimisation of flow behaviour for large collector arrays
Investigation of boundary conditions that require pressure equalisation
Computer based tool optimising building process
Integration of valves in single absorbers
Self-adjusting valves for matched-flow
Expansion of bionic structures to the full building skin
Special solutions, multifunctional façades
Switchable layers
Switchable absorbers
Switchable (semi-)transparency
Switchable energy management
Easy certification for innovative multifunctional building envelopes
Solar thermal activation of innovative architectural concepts
Vacuum insulating glass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2050
SAH standard for building stock
20 - 34 % of all buildings heat demand covered by (BI)ST
BIST and heat networks integrated into national or international energy system
BIST in standard tools for urban planners
NON-TECHNICAL
Questions of stakeholders
Dissemination & translation of existing know-how e.g. via [4]
Include BIST in education & training
Include in architects' fee structure
Choice of technology, dimensioning for most typical cases (residential)
For special collectors and buildings
Software & simulations
In depth analysis allocating BIST technology to dedicated application, taking building physics into account
Simulations & optimisation on district level
Consider heat networks
Consider glare
Derive rules of thumb, easy-to-use interfaces
New business models & boundary conditions
Optimized cooperation of the stakeholders and sales structure
Recommendations for product placement, calculation of risk (insurance)
Optimized public support for market-penetration

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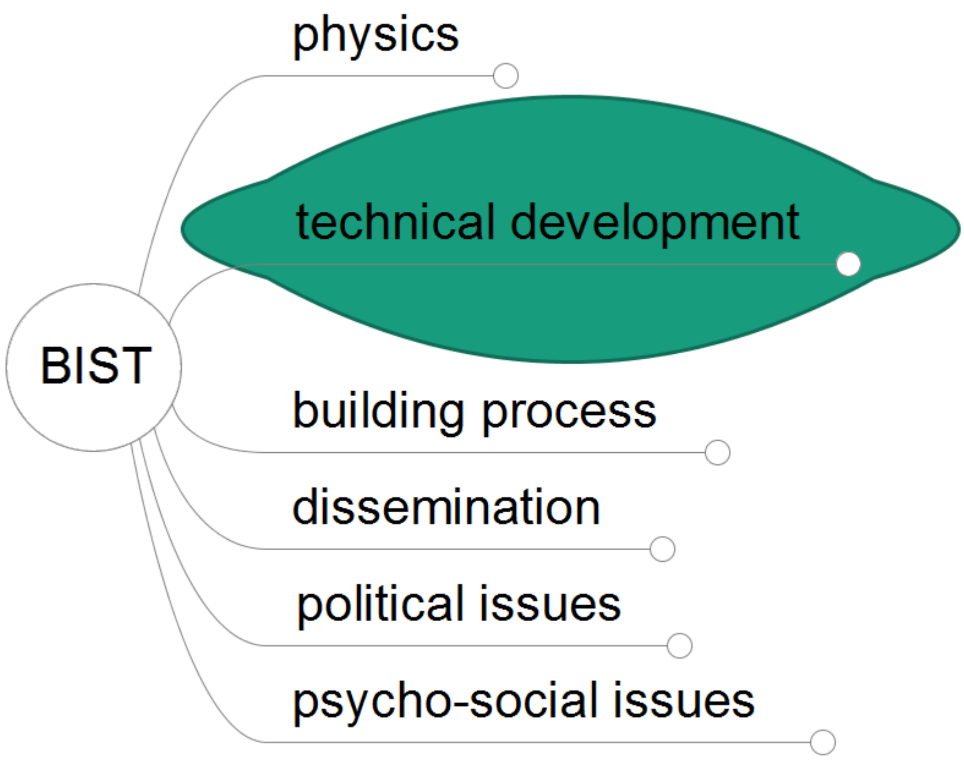
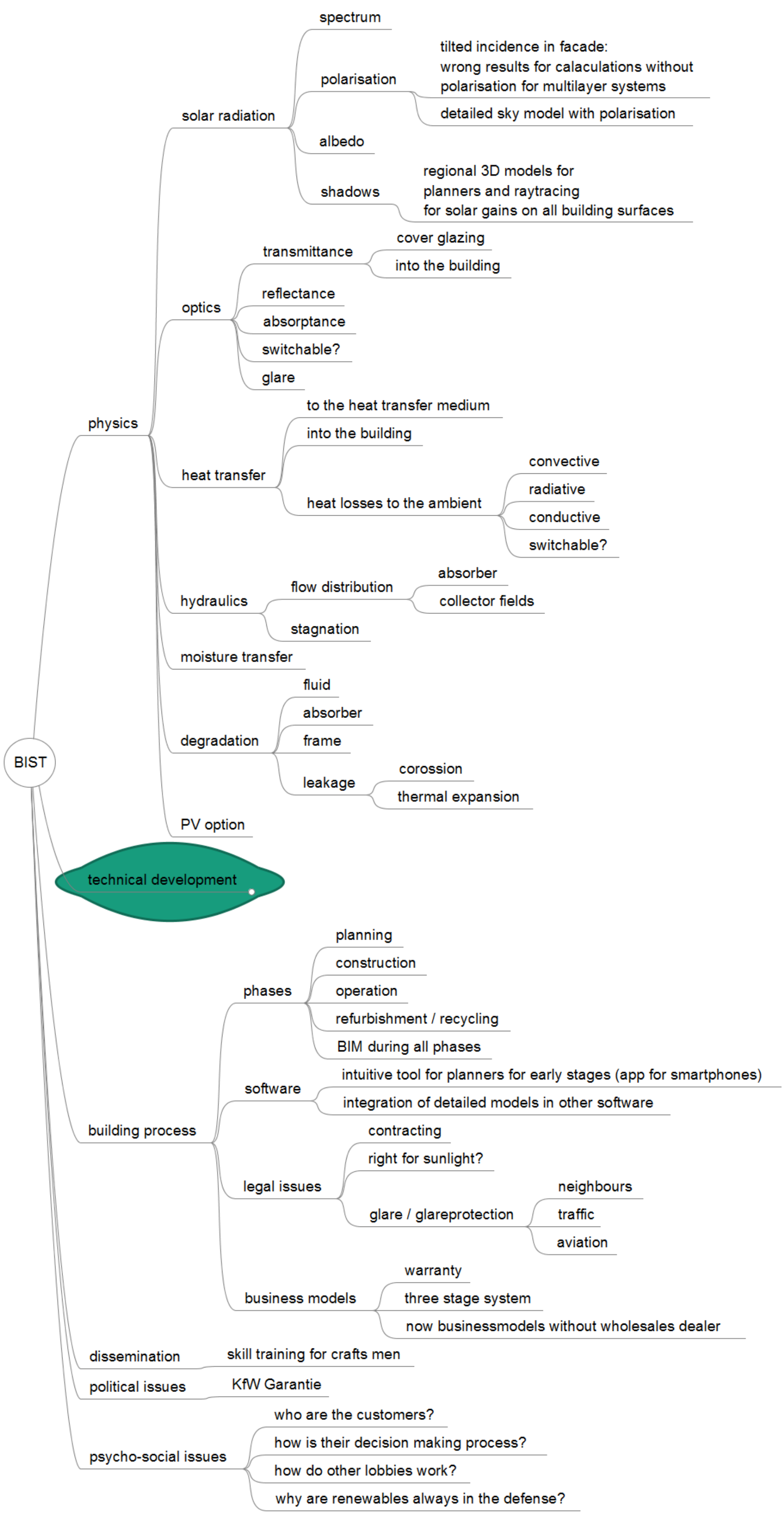
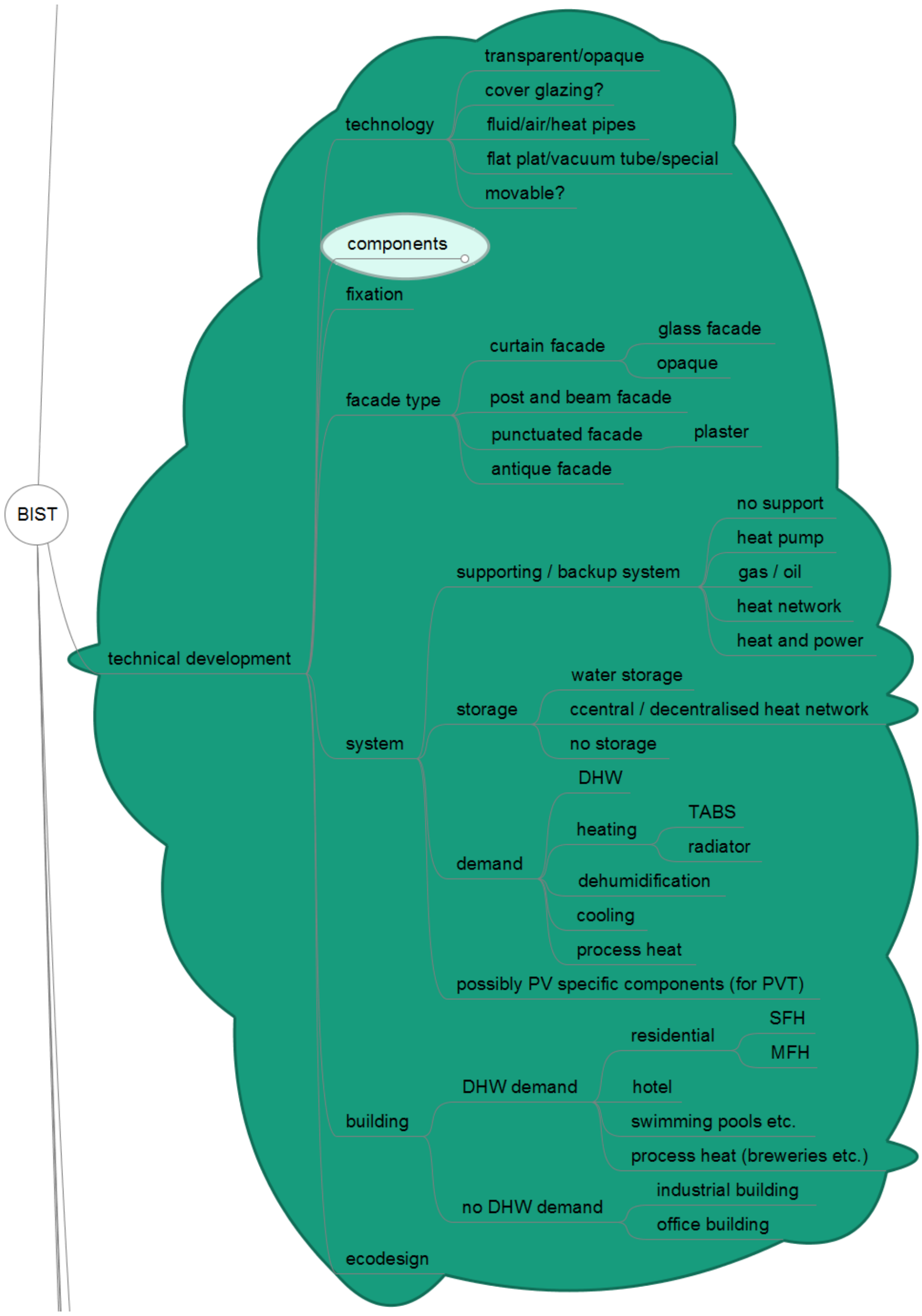
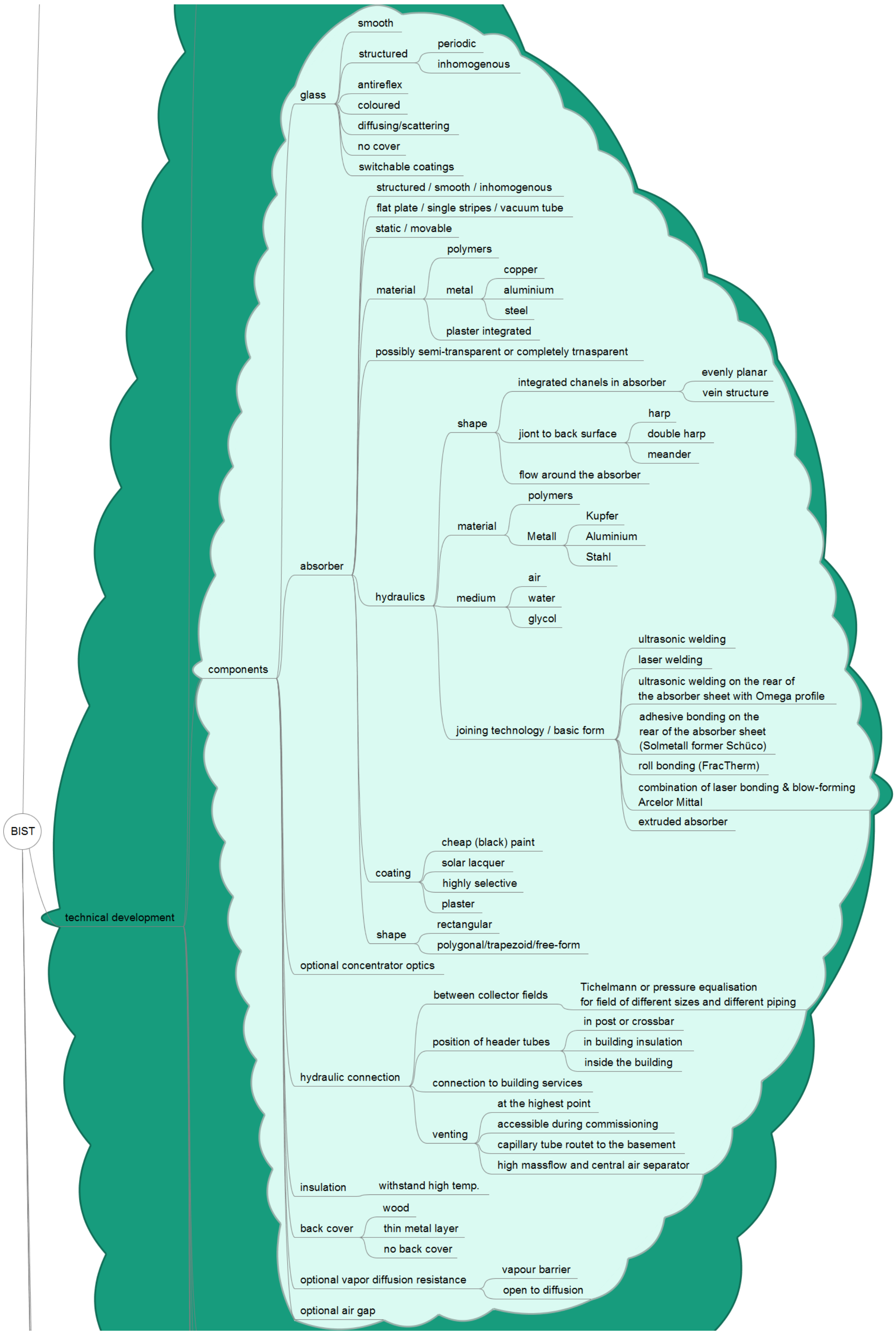
8 Appendix

Mind map of the parameter space




BIST
physics
solar radiation
spectrum
polarisation
tilted incidence in facade:
wrong results for calaculations without
polarisation for multilayer systems
detailed sky model with polarisation
albedo
shadows
regional 3D models for
planners and raytracing
for solar gains on all building surfaces
optics
transmittance
cover glazing
into the building
reflectance
absorptance
switchable?
glare
heat transfer
to the heat transfer medium
into the building
heat losses to the ambient
convective
radiative
conductive
switchable?
hydraulics
flow distribution
absorber
collector fields
stagnation
moisture transfer
degradation
fluid
absorber
frame
leakage
corossion
thermal expansion
PV option
technical development
building process
phases
planning
construction
operation
refurbishment / recycling
BIM during all phases
software
intuitive tool for planners for early stages (app for smartphones)
integration of detailed models in other software
legal issues
contracting
right for sunlight?
glare / glareprotection
neighbours
traffic
aviation
business models
warranty
three stage system
now businessmodels without wholesales dealer
dissemination
skill training for crafts men
political issues
KfW Garantie
psycho-social issues
who are the customers?
how is their decision making process?
how do other lobbies work?
why are renewables always in the defense?


BIST
technical development
technology
transparent/opaque
cover glazing?
fluid/air/heat pipes
flat plat/vacuum tube/special
movable?
components
fixation
facade type
curtain facade
glass facade
opaque
post and beam facade
punctuated facade
plaster
antique facade
system
supporting / backup system
no support
heat pump
gas / oil
heat network
heat and power
storage
water storage
ccentral / decentralised heat network
no storage
demand
DHW
heating
TABS
radiator
dehumidification
cooling
process heat
possibly PV specific components (for PVT)
building
DHW demand
residential
SFH
MFH
hotel
swimming pools etc.
process heat (breweries etc.)
no DHW demand
industrial building
office building
ecodesign


BIST
technical development
components
glass
smooth
structured
periodic
inhomogenous
antireflex
coloured
diffusing/scattering
no cover
switchable coatings
absorber
structured / smooth / inhomogenous
flat plate / single stripes / vacuum tube
static / movable
material
polymers
metal
copper
aluminium
steel
plaster integrated
possibly semi-transparent or completely trnasparent
hydraulics
shape
integrated chanels in absorber
evenly planar
vein structure
jiont to back surface
harp
double harp
meander
flow around the absorber
material
polymers
Metall
Kupfer
Aluminium
Stahl
medium
air
water
glycol
joining technology / basic form
ultrasonic welding
laser welding
ultrasonic welding on the rear of the absorber sheet with Omega profile
adhesive bonding on the rear of the absorber sheet (Solmetall former Schüco)
roll bonding (FracTherm)
combination of laser bonding & blow-forming Arcelor Mittal
extruded absorber
coating
cheap (black) paint
solar lacquer
highly selective
plaster
shape
rectangular
polygonal/trapezoid/free-form
optional concentrator optics
hydraulic connection
between collector fields
Tichelmann or pressure equalisation for field of different sizes and different piping
position of header tubes
in post or crossbar
in building insulation
inside the building
connection to building services
venting
at the highest point
accessible during commissioning
capillary tube routet to the basement
high massflow and central air separator
insulation
withstand high temp.
back cover
wood
thin metal layer
no back cover
optional vapor diffusion resistance
vapour barrier
open to diffusion
optional air gap