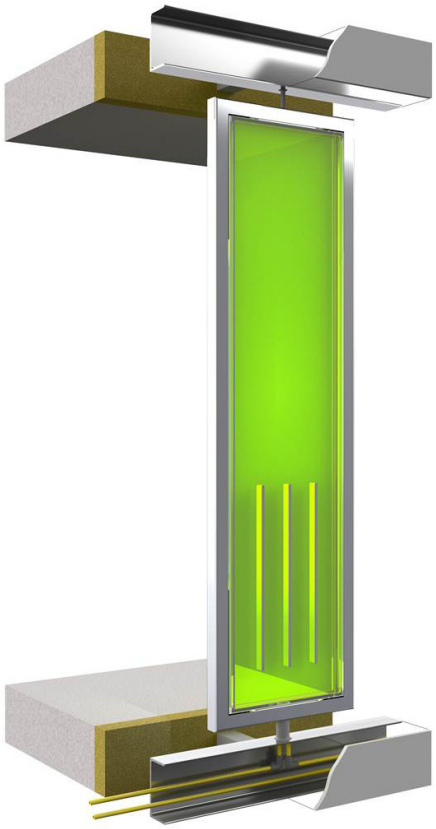

SUMMARY REPORT

RESEARCH REPORT
VENTILATED FACADE SYSTEM WITH INTEGRATED PHOTOBIOREACTORS

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FORSCHUNGSINITIATIVE Zukunft BAU

ARUP COLT SSC Strategic Science Consult GmbH

SUMMARY REPORT

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VENTILATED FACADE SYSTEM WITH INTEGRATED PHOTOBIOREACTORS

SUMMARY

The secondary façade system developed in the current research project integrates photobioreactors (PBR) to allow for a building integrated generation and utilization of biomass from microalgae and solar thermal heat.

Between December 2010 and March 2013 the research project was conducted by a consortium consisting of the companies Arup Germany GmbH, Strategic Science Consult GmbH and Colt International GmbH partly funded by the research initiative ZukunftBau

The functional prototype facade system comprises a PBR-panel, the necessary supply system and a substructure for transfer of the occurring loads into the primary structure of the building. Besides all necessary connections for media and compressed air the PBR-panel is equipped with a custom sensor for the filling level. The supply system can be invisibly installed in the substructure to service the individual PBR-panels. The system is optimized both statically and thermally to ensure the optimal biomass and energy yields.

In January 2012 first prototypes of the developed system were installed for testing and optimization at SSC´s pilot plant in Hamburg Reitbrook. In January 2013 a functional cluster of six optimized photobioreactors (PBR) was installed and successfully put into operation.

The first building integrated pilot installation of the developed PBR-facade system with an active area of 200 m² was launched in March 2013 at the BIQ-building as part of the International Building Exhibition in Hamburg (IBA).

1. INTRODUCTION

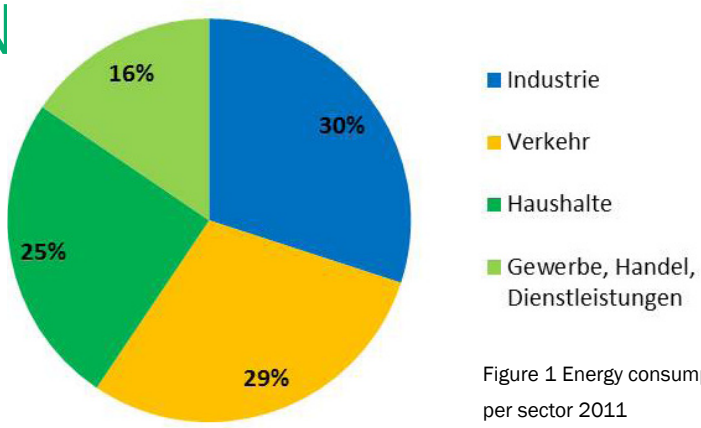


Figure 1 Energy consumption in Germany per sector 2011 (BMWi, 2012)

1.1 Background

In many industrialized countries and especially in the European Union the energy policy is driven towards an increased use of renewable resources (referred to as "renewables") by the public sector. Germany globally takes a leading role in these efforts. With legally binding steps and measures such as the nuclear power phase-out and mandatory zero-energy house standard for new buildings from 2020 on, Germany shows determined efforts to advance the transformation of the power supply in Europe. The overall aim is to decrease emissions of CO_2 emissions while reducing the dependency on fossil energy sources at the same time.

The crucial factors for a successful use of renewables for the generation of energy are an on-demand supply as well as an efficient distribution system. Besides other advantages biomass from micro-algae offers good storability and transportability both crucial for providing a sustainable on-demand energy supply.

The energy balance of a building as one of the crucial factors defining the energy performance can be improved by reducing energy consumption as well as generating energy in building associated. The bioreactive façade system developed in the current research project represents a promising alternative to established technologies such as photovoltaics for using building associated areas for the generation of renewable energy.

Unicellular micro-algae are cultivated in an aqueous environment and generate biomass through photosynthesis when sufficient amounts of sunlight, CO_2 and nutrients are available. Systems for the cultivation of biomass from micro-algae can be generally separated into open and closed types. Closed systems such as flat panel photobioreactors can achieve significant increases in effectiveness and efficiency over open systems by improving the surface-to-volume ratio of the culture medium. Also highly efficient PBR designs with low structural depths can be realized. Closed systems offer the possibility of incorporating agitation systems with high flow velocities that allow an increase of the active media fraction and a significant reduction of bio-fouling risk. A highly efficient flat panel photobioreactor (PBR) was developed and patented by the project partner SSC GmbH as part of their research on technologies for exploring the resource micro-algae

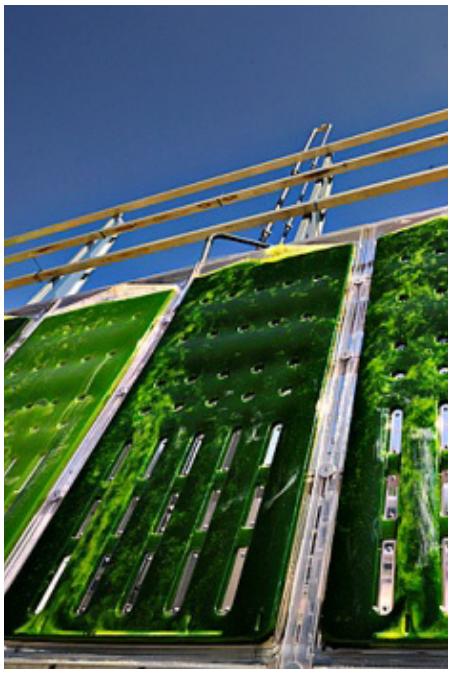


Figure 2 TERM Flat Panel Photobioreaktor Technology © SSC GmbH

(TERM). The flat design together with its high efficiency enables the TERM PBR technology to be applied on building areas for example on walls or on rooftops. This potential gives rise to possibility of a building integrated cultivation and the utilization of the renewable resource biomass in urban areas.

1.2 Research Project

This research project is intended to develop a feasible system for the building integrated cultivation of biomass from microalgae to make this resource accessible for Germany. The aim of the research project is the development of a ventilated façade system featuring photobioreactors (PBR) with single-axis deployment for the cultivation of micro-algae and the capture of solar thermal heat on the building envelope. Micro-algae biomass as well as solar thermal heat is utilized to support the building´s energy demand and improve the overall energy balance of the building.

1.2.1 Consortium Partners

Arup Deutschland GmbH is the coordinator and design manger of the project coordinating the activities of all partners and providing specialist engineering and consultancy services in the field of materials science, façade engineering, building physics, glass design, building automation and services deign.

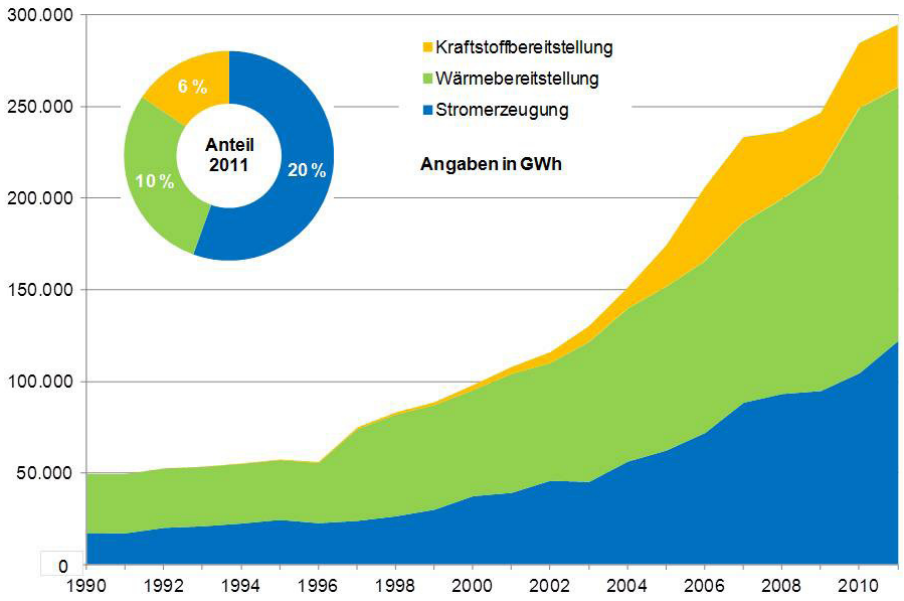
SSC Strategic Science Consult GmbH is responsible for providing and developing the photobioreactor (PBR) and micro-algae technology. In particular, this includes process management, operation and optimization of prototypes and test facilities and the collection and analysis of data. In addition, SSC provides specific design services in areas concerning the integration of the technology into the façade system.

Colt International GmbH is responsible for the facade and deployment technologies. In particular, the generation of detail design and shop drawings for prototypes and test bodies including the components required for deployment. Additionally Colt is responsible for the manufacturing and assembly of any prototypes including the substructure and connections to the primary building structure.

1.2.2 Approach

First, a basic evaluation of the various design requirements and parameters is conducted and an outline specification for the system is created. The outline specification includes all requirements resulting from micro-algae cultivation and the featured photobioreactor (PBR) technology as well as structural and regulatory requirements. Based on the outline specification and the definition of additional objectives and design parameters a feasible concept for a “ventilated facade system featuring PBR” is developed. According to the concept design a detailed design is developed and prototypes are manufactured. Prototypes of the facade system are tested under field conditions with the results feeding back to further optimization and development. Flanging the system hardware an integrated energy management and a corresponding control system are developed.

Figure 3 Renewables in Germany (AGEE-Stat, 2012)



2. OUTLINE SPECIFICATION

Requirement	Value
Building physics	▪ Rain
Structural	▪ Transfer of Loads (dead loads, wind loads) ▪ Durability ▪ Residual load bearing capacity
Building Roster	▪ Variable up to 1500 mm
Energy design	▪ Optimum Biomass output / CO_2-capture ▪ Optimum heat output
Building services	▪ Heat storage ▪ External CO_2-source necessary
Asthetics	▪ Translucency / semi-transparency ▪ Visible frame depth

Table 1 Overview requirements for an application in residential buildings

The development focusses on a secondary façade system, thus there are no requirements for insulation, weathering protection and shading. The facade system was developed exemplarily for a residential building where the most onerous requirements were identified to ensure ease of transfer to other building types. German wind load zone 2 and a building height of up to 25 m were defined as the load case to inform design and verification.

An overview of the requirements gathered for a corresponding building application is shown in Table 1. The relevant design requirements for the cultivation of micro-algae and the use of the TERM photobioreactor (PBR) technology are summarized in Table 2 and 3.

All relevant German Standards and Guidelines for load assumptions, glass and glazing systems as well as metal construction, fire protection and noise were used for the design development. A detailed overview is given in the full final report.

Requirement	Value
Culture-Medium	Water, aqueous medium
Operating temperature	8 - 32 °C
Favored spectral range	around 680 nm
Nutrients	CO_2, Nitrate, Phosphate
Compatibility	Bio-compatible materials, no cell membrane disrupting agents allowed (detergents, solvents, etc.)

Table 2 Requirements for the cultivation of micro-algae

Table 3 Requirements Flat panel photobio-reactor technology

Requirement	Value
Dimensions PBR-unit	floor high
Format	Portrait - Hight >> Width
Depth PBR-cavity	15 – 25 mm
Hydrostatic pressure	Loads according to height of water column have to be supported.
Tightness	Tightness of the PBR-cavity has to be ensured.
Dimension AirLift-fillets	Height - ~ 1/3 total height PBR-unit Width – as slender as possible
Distance AirLift-Fillets – bottom edge PBR-cavity	~ 50-100 mm
Width AirLift-channel	~ 150 mm
AirLift-pressurized air	Pressure has to overcome hydrostatic pressure occuring at bottom edge of PBR-cavity.
Connections	Medium intake Medium outlet Pressurized air Ventilation
Supply System	Closed loop system
Interconnection of PBR-Units	In series, clustered

3. CONCEPT DESIGN

The aim of the concept design development is to ensure the feasibility of the system for the building integration of existing flat panel photobioreactor (PBR) technology including supply and utilization systems. The overall concept consists of two main parts: an external system on the buildings outside and a supply and utilization system that is integrated into the building services.

The outline specification created in the first step together with the definition of objectives and design parameters provided the basis for the development of a feasible concept design. The objectives were determined with regard to environmental, energy, economical, architectural and design aspects. The design parameters identified include the location of the PBR on the building, orientation, deployment, the panel assembly and the load-bearing systems as well as the selection of suitable materials.

A façade position is favourable over roofs as integrated functionalities such as bio-adaptive shading can open additional benefits. A comparative simulation of solar irradiation for Hamburg showed a benefit for south facing façade areas and a favourable centred vertical axis for deployment. Due to advantageous loads the panel assembly was chosen to be "horizontally adjacent".

Figure 4 shows the final concept design for the facade system.

1 - Primary Support Structure

- Structural building frame to which the secondary support system is attached and all loads are transferred.

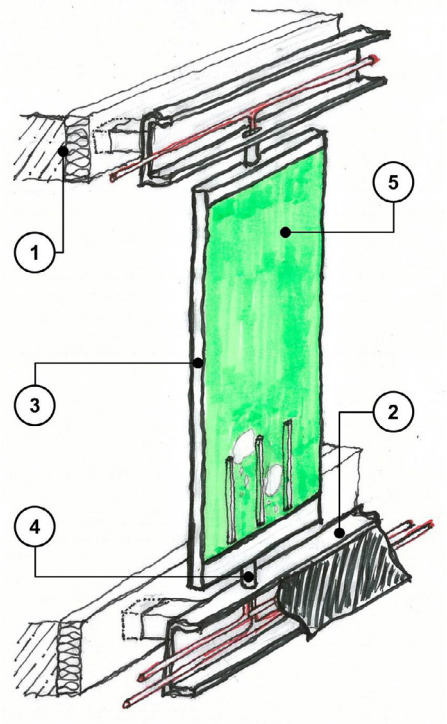
2 - Secondary Support System

- Floor wise transfer of occurring loads to the primary building structure (dead loads, wind loads)
- C-section for invisible installation of the supply system with accessibility for revision

3 - Tertiary Support System

- Four-sided, mechanically clamped frame to ensure the tightness of the PBR-unit (hydrostatic pressure of the medium)
- Transfer of the occurring loads (dead load, wind load) to the secondary support system
- Incorporation of the secondary seal level to reduce the risk of leakage

Figure 4 Sketch of PBR-Facade Concept
© Arup Deutschland GmbH



4 - Deployment

- Central pin bearings and vertical bar to fix the PBR-panel
- Hollow pins for kink free pipe housing
- Simultaneous control of several PBR-panels (PBR unit and tertiary support system) via pushing rods and linear drives

5 - Photobioreactor-Unit (PBR)

- Safety glass for front and rear reactor wall

- Transfer of loads from hydrostatic pressure of the medium
- Circumferential spacer incorporating primary seal and necessary connections
- Vertical fillets to facilitate medium agitation (AirLift)
- Thermal insulation through use of double glazed units and low emissivity coatings

The building integration of the façade system was achieved throuhg a closed-loop system incorporating and connecting all relevant functionalities (biomass and heat generation and harvesting, supply system for PBR-units, utilization or storage of energy).

A schematic representation of the building integration concept of the overall system is shown in Figure 5. In addition, a feasible concept for the supply and circulation system was developed which can be adapted to the individual application. The result for a typical option is shown in Figure 6.

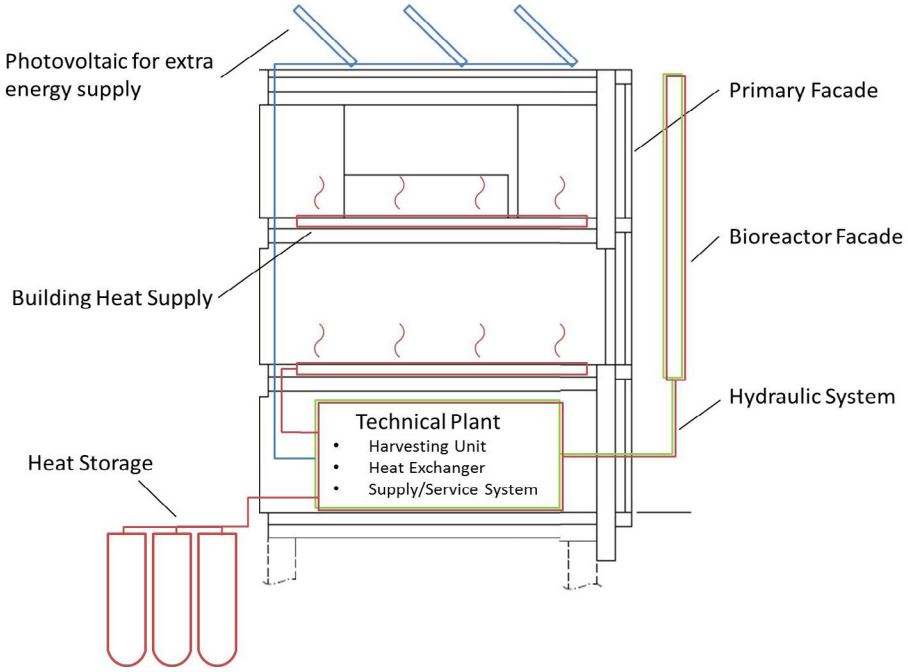


Figure 5 Schematic representation Building Integration Concept
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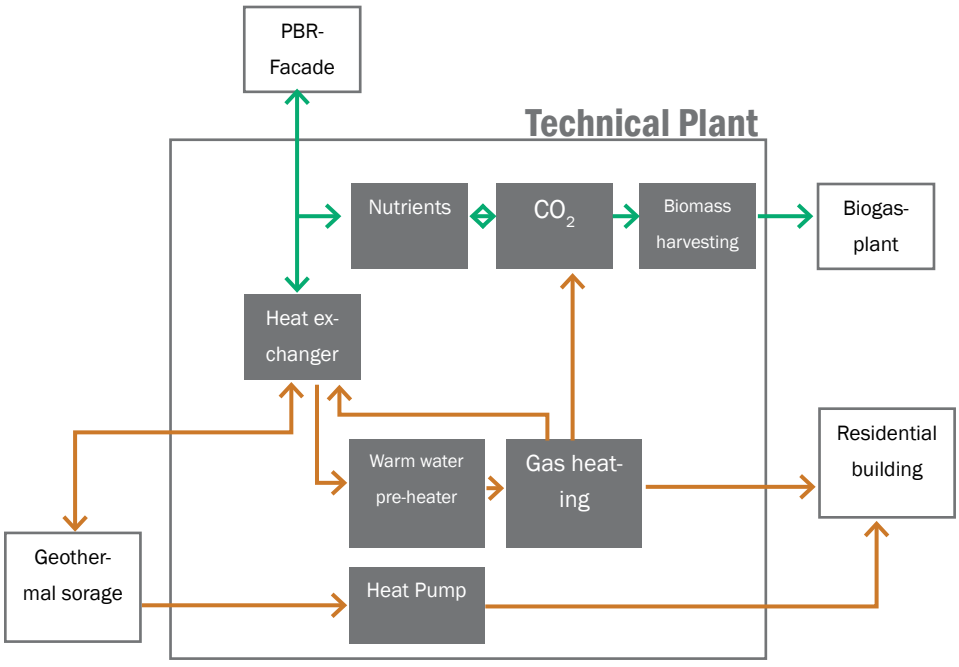

Figure 6 Schematic representation Technical Plant Integration Concept
© Arup Deutschland GmbH

4.
FACADE SYSTEM

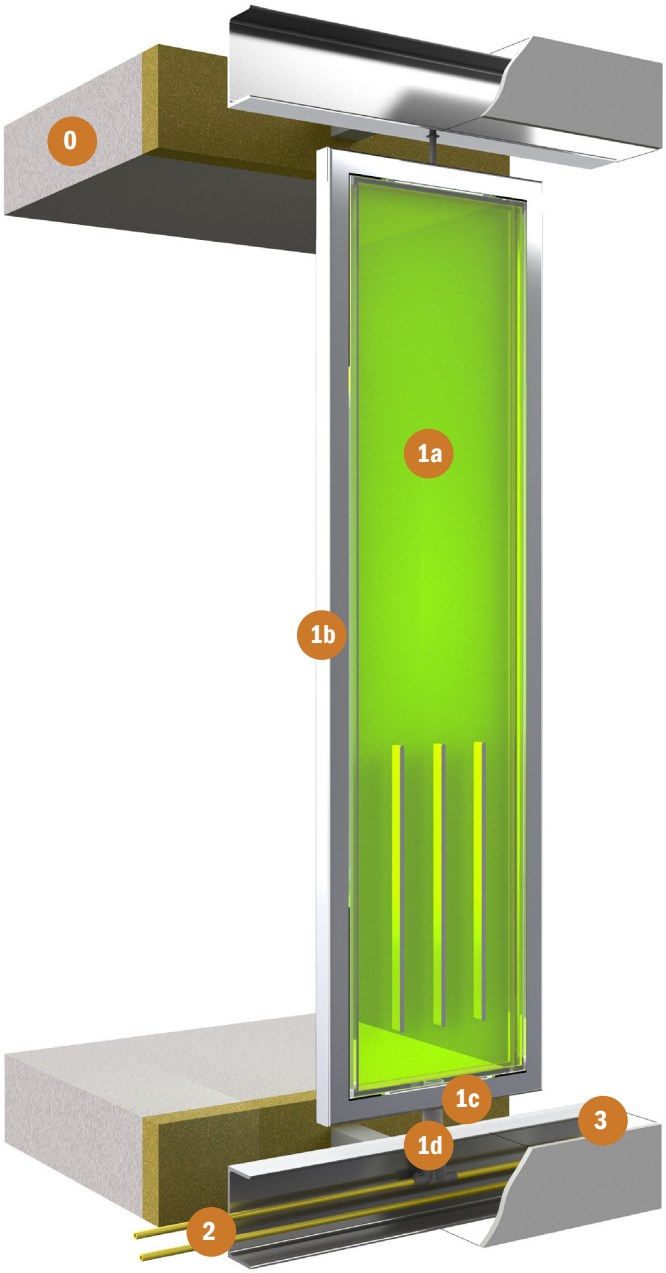

Figure 7 Rendering of the Final PBR-panel Prototype including support structure and supply system
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Based on the concept design several prototypes of a facade system integrating photobioreactors (PBR) were developed, planned and built. Intensive performance testing was conducted on the various prototype generations and results were fed back for optimization towards a functional overall system. Figure 7 shows the result.

The functional modules of the façade system can be described as follows (Figure 7):

- 0 - Primary building structure
- 1 – PBR-panel
- 2 - Supply system
- 3 – Support structure - Horizontal load collectors including connections to the primary building structure

Due to the complexity of the “PBR panel” the assembly was further divided into the following sub-units:

- 1a – Photobioreactor-unit (PBR without frame)
- 1b - Four-sided frame
- 1c – Bearing for the PBR-unit / load transfer into the support structure
- 1d - Connections and housing of supply system

5. PROCESS MANAGEMENT AND PROCESS CONTROL

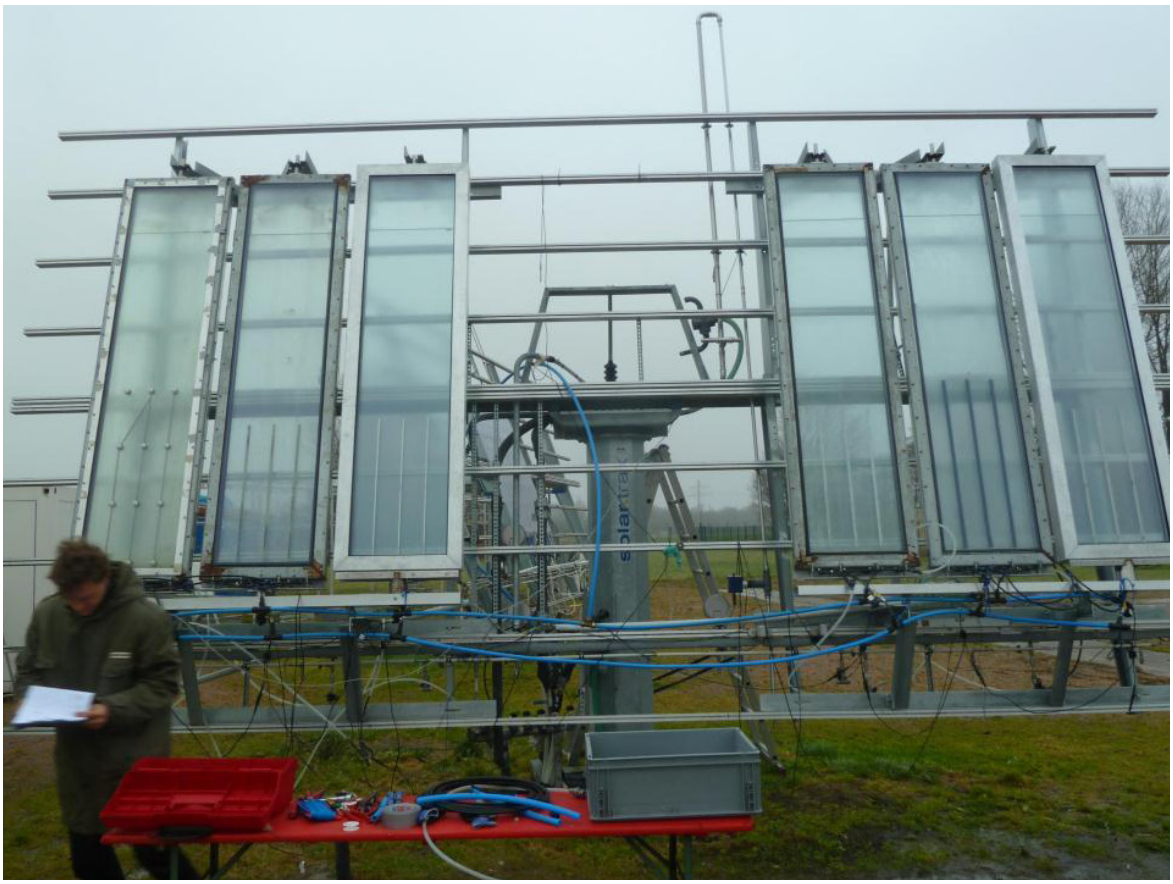

Figure 8 Generation one and two Prototypes at the pilot plant.
© SSC GmbH

The hydraulic system was implemented as a closed loop system. By integrating all relevant functions in the closed loop system a complex process management and control system is necessary to enable the effective and efficient operation of the facade system.

The system-relevant parameters for process management and control were determined through extensive prototype testing types and optimized for biomass and heat output. In particular, the optimal flow rate was determined with regards to process parameters such as flow, supply (CO_2, sunlight, nutrients, heat) and utilization capability (biomass and heat extraction). The results were used to inform and optimize the process control system.

6. ENERGY PERFORMANCE

Figure 9 Installed PBR-Facade System at the BIQ-building
© Colt International GmbH

Calculations and simulations as well as prototype experiments yielded characteristics such as heat transfer coefficients and production rates that inform the performance of the façade system. Here an increase in biomass output by 100 % was achieved by incorporating special glass with ultra-high transmission from the photovoltaic technology. The results show that the developed facade system can achieve a conversion rate of the incident solar energy of 38 % to heat and 10 % to biomass.

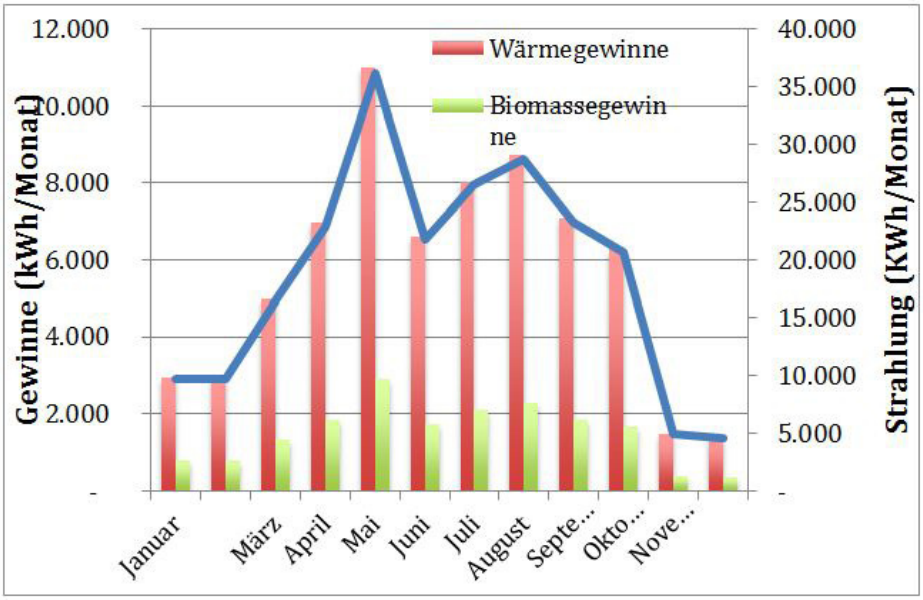

Figure 10 Monthly irradiation into the PBR and according biomass / solar heat yields for an active area of 312 m² and south-west orientation
© SSC GmbH

Figure 11 Rendering BIQ-building
© SSC GmbH

7. OUTLOOK

The immediate outlook for the PBR-façade system is the implementation of an extensive monitoring of the pilot project BIQ. The BIQ-building was presented to the public in March 2013 at the International Building Exhibition (IBA) in Hamburg and features an active facade area of about 200 m^2. The monitoring will be carried out over a period of two years by the consortium partners and the HafenCity University Hamburg with funding from research initiative Zukunft-Bau. Technical and energy performance as well as user-oriented considerations and the interaction of the three fields will be evaluated during the monitoring phase. The findings will be fed back to the façade system to inform further development and optimization.

In addition, variations and further developments of the system will be pursued. For example structural adhesive connections for load transfer within the PBR-unit will be examined.

In the long-term promising potentials for the technology can be identified in the field of energy efficient construction and retro fit of existing buildings. Especially future concepts for urban planning will be dependent on developing multi- and inter-building concepts connecting mass flows of heat, electricity, water and CO_2 with the aim to efficiently generate, store and supply energy according to consumer demands. Here the innovative PBR-façade technology demonstrates the potential of combining technical and biological cycles to achieve carbon neutral and zero-energy settlements.