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Joint Research Project (in progress): Draft Standard for Determining the Thermal Stress of Glass and Glass-Glass PV Modules (BIPV) in the Construction Industry

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Abstract

For the design of façade and roof glazing, loads due to dead weight, climatic loads (IGU - pressure differences), wind and snow are well investigated and are considered in engineering practice. However, glass constructions are also ex-posed to thermally induced stresses due to direct solar irradiation. The standards and guidelines available so far, both nationally and at the European level, are partly outdated or contain only simplified instructions and specifications for calculating thermally induced stresses of façade and roof glazing. Within the research project, a variety of façade glazing configurations and additionally building-integrated (BIPV) glass-glass photovoltaic modules, for example as a façade cladding rear ventilated, are being investigated by means of numerical simulation and subsequent experimental validation with up-to-date German meteorological data. The purpose of the project is to reduce or prevent the occurrence of thermally induced glass breakage (thermal breakage) through European standardization. In this way, economic damage can be avoided. The present paper provides an insight into the two-years lasting joint research project, including the current status of science and technology, goals, structure and process, and descriptions of work packages. Results, such as the collection of the various influencing factors, meteorological data, and results from numerical simulations, will be presented after the project has finished at the end of September 2022.

Keywords

Thermally induced stresses, thermal breakage, façade glazing, insulating glass unit, building-integrated (BIPV) glass-glass photovoltaic modules, German meteorological data

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1. State of the art in science and technology

Due to many cases of damage, research projects have already been carried out in the past to determine the thermal stress on façade glazing, but these have not been incorporated into national and European standards.

As a result of the efforts and measures surrounding the energy policy change, building-integrated photovoltaic modules (BIPV modules) are becoming increasingly important as a component of an energy-efficient, solar building envelope, so there is also a growing need for research in this area.

The Institute of Structural Mechanics and Design (ISM+D), as a representative of the Technical University of Darmstadt, has carried out some well-founded preliminary studies (not published) to clarify the problem regarding the thermally induced stresses on façade glazing, which are based on numerical calculations and current weather data. In the preliminary work of ISM+D, double and triple insulating glazing units with a façade orientation towards the south-east were considered. The stress states induced by thermal loading were determined based on selected critical combinations of temperature and radiation depending on the façade orientation, the season and the resulting temperature field in the glass plane. A test reference year (TRY 2011) of the German Meteorological Service (DWD) for the site of Potsdam was used as a basis. The combination of morning sun (high irradiation) and cold night was considered when deciding on the critical façade orientation of south-east. Considering the material properties of the different components of the glazing units (glass, spacers, sealant), the stress field in the glazing was calculated.

The investigations have shown that stress concentrations occur at the glass edges and thus a normatively regulated procedure is necessary to determine the thermal stress for glass in the building industry. According to the numerical investigations, most of the investigated configurations of the insulating glass units should not be constructed with float glass, as the permissible edge strength of 36 MPa [DIN 18008-1 2020] is exceeded here. These insulating glass units require the use of toughened safety glass in order to justify implementation without further testing.

A published paper by AGC Interpane and AGC Glass Europe [Polakova et al. 2018] describes and compares the design methods currently used in practice (French standard NF DTU 39 P3). The advantages and disadvantages of the French standard are highlighted there and points that need to be updated and generalised are elaborated. Furthermore, numerical calculations based on different sets of meteorological data are performed and compared in this paper. It has been shown there that the applied meteorological data sets lead to different results. Therefore, the meteorological data must be comprehensively evaluated and the resulting stresses on the façade glazing must be assessed.

The following examples of relevant literature exist:

- Glass damage: surface damage, glass breakage in theory and practice [Wagner 2020].
- Glass construction: fundamentals, calculation, construction [Schneider et al. 2016].

Furthermore, there are several leaflets that point out the problem and mention possible influencing factors, for example:

- Thermische Beanspruchung von Glas (thermal stress on glass) [Flachglas Schweiz 2021].
- AGGA Technical Fact Sheet - Thermal Stress Glass Breakage [AGGA 2015]
- Thermische Beanspruchung von Gläsern in Fenstern und Fassaden (thermal stress on glass in windows and façades) [VFF 2012]
- CNR-DT 210 (Italian Guideline) [CNR-DT 210 2013]
- NF DTU 39 P3 (French Standard) [NF DTU 39 P3 2006]

In summary, the initial situation can be described as follows:

- There is a lack of well-founded and freely available meteorological data sets or a meteorological map (maximum radiation-temperature map) for Germany and Europe on vertical facades
- From expert practice: Many cases of damage occur as a result of thermally induced loading in the case of:
  - Insulating glass units with certain combinations of solar control/thermally insulating coatings (mostly triple insulating glass units) and
  - building-integrated photovoltaic modules, mostly CIGS thin-film modules (for technological reasons, e.g., use of drilled float glass).
- Risk assessment in the context of thermal stress analyses currently re-quires a great deal of effort because the boundary conditions (planning and usage details are often unclear) are not standardised for the calculation. This also leads to different results.
- Currently, due to the lack of alternative calculation methods, the French standard [NF DTU 39 P3 2006] in combination with Vitrages Décision software) and the English model (John-Colvin method) are used for the whole of Europe. However, it is unclear which method is the correct one for façade glazing or BIPV modules.
- There is a lack of uniformly defined procedures for the calculation (e.g., stationary or transient, time period considered, etc.) and assumptions for the simulation parameters.
- Common practice: A purely qualitative or general dimensioning of glazing structures is carried out by using single-pane safety glass (thermally toughened glass). Regarding BIPV modules, the issue of thermally induced stress is usually neglected.
- For Germany, no validated software for thermal stress calculation is currently available on the market.

2. Aims of the project

This results in the following objectives for this project:

- Development of a universally usable radiation-temperature map (Germany / division into radiation zones),
- Categorisation of the parameters, for example, meteorological data, shading, construction, façade orientation, etc. (using a checklist) inducing thermal breakage in glass structures and in BIPV,
- Development of a unified, simplified and numerical calculation method,
- Preparation of a (European) draft standard on thermally induced stresses in façade glazing and building-integrated (glass-glass) photovoltaic modules, in order to enable economic design and to avoid cases of damage,
- Creation of a basis for the development of calculation software.

3. Structure of the project

The project contains seven work packages:

- WP 1: Definition of scope and relevant parameters,
- WP 2.1: Evaluation of relevant meteorological data sets,
- WP 2.2: Specific evaluation in relation to the calculation method,
- WP 3.1: Investigation by numerical simulation,
- WP 3.2: Development of a calculation method (numerical and simplified by means of manual formulae),
- WP 4: Experimental validation program,
- WP 5: Preparation of a draft standard.

The joint research project consortium consists of Interpane Entwicklungs- und Beratungsgesellschaft mbH GmbH, Sunovation Produktion GmbH, Fraunhofer Institute for Solar Energy Systems ISE and Technical University of Darmstadt - Institute of Structural Mechanics and Design (ISM+D).

Figure 1 shows the project overview with each work package and their interactions. Also, the iterative approach between work packages 2.1, 3.1, 2.2, and 3.2 is shown. The project schedule is presented in Figure 2.

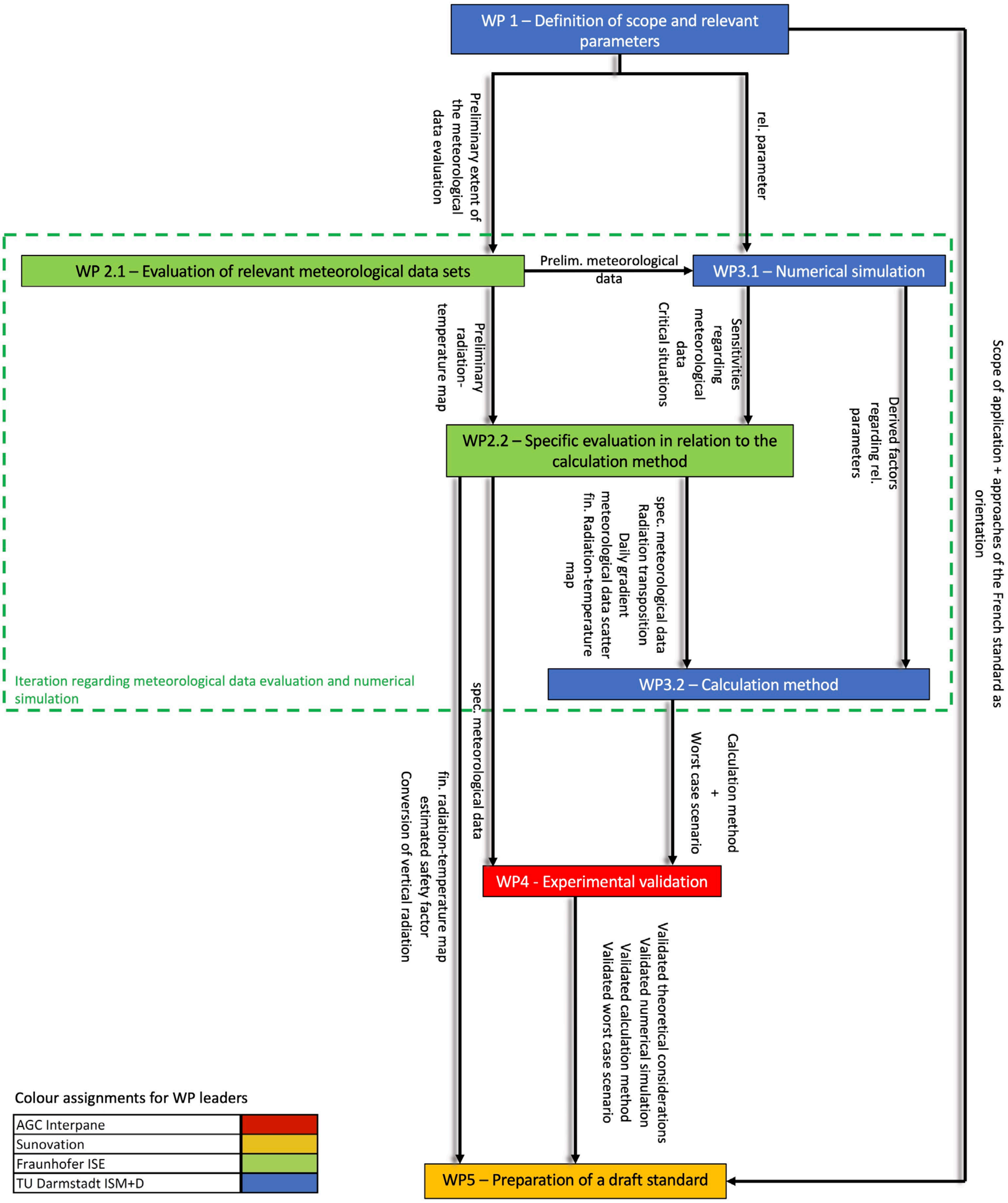

Fig. 1: Project structure overview.

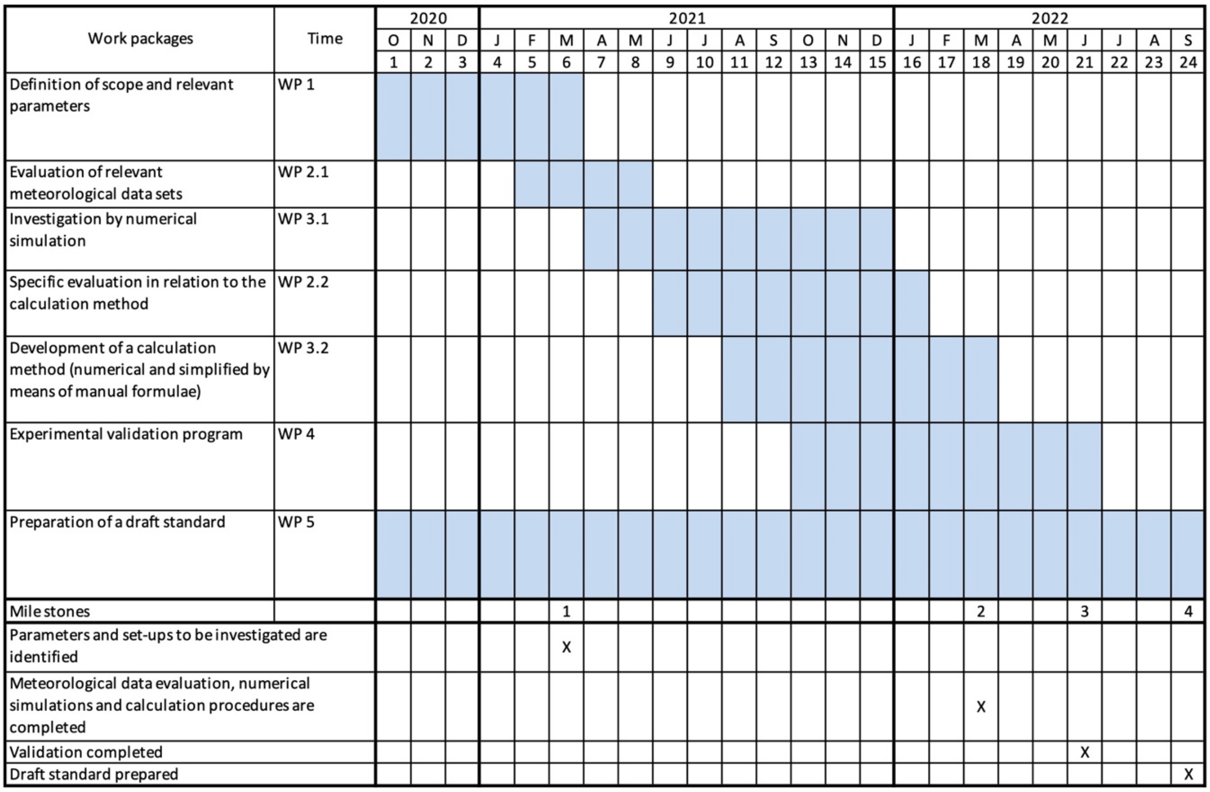

Fig. 2: Project schedule.

4. Aim and description of the work packages

In WP 1, the scope of application for each standard regarding glass structures and building-integrated glass-glass PV modules (BIPV) with their different objectives and contents will be determined. In addition, current experience from engineering practice on thermal stress analysis, the presentation of the state of the art in science and technology as well as findings from cases of damage are summarised. Questions are to be clarified such as: Which relevant influencing parameters (for example, meteorological data, shading, construction, façade orientation, etc.) inducing thermal breakage in glass structures and in BIPV are to be selected, or (provisionally) categorised? In which framework and with which parameters is the evaluation of meteorological data carried out?

One focus of this project is the development of well-founded, relevant and freely available meteorological data sets that will ultimately result in a universally usable meteorological map (radiation-temperature map) for Germany. In WP 2.1, the relevant meteorological parameters are identified and evaluated in their variation regarding season, spatial distribution and both temporal and spatial resolution. For this purpose, the correlation of radiation data and temperature values is analysed. Which radiation-temperature combinations, de-pending on area and season, are characteristic for glass breakage? First, preliminary data sets are used in WP 3.1 in an iterative process to carry out orienting numerical simulations of the thermal load on glazing and BIPV structures.

Within WP 3.1, the sensitivities of the influencing parameters are determined and finally categorised with the preliminary meteorological data sets from WP 2.1 for both conventional glazing structures in façades and BIPV modules. On the one hand, factors can be derived that enable a simple manual calculation and stationary calculation as opposed to a complex transient calculation (cf. WP 3.2). On the other hand, the determined sensitivities serve to iteratively specify the meteorological data sets in WP 2.2.

In WP 2.2, the final version of the meteorological data (radiation-temperature map) is to be refined regarding the calculation procedure. In this respect, the scatter for estimating a safety factor as well as the probability of occurrence of the thermal load for façade glazing and glass PV modules will be derived.

Using the specified meteorological data (radiation-temperature map) from WP 2.2, valid calculation methods for façade glazing and BIPV modules will be developed in WP 3.2. The conversion from 3D-transient calculation to a simple manual calculation with factors such as geometry, shading, radiation, and temperature effects, etc. will be carried out. Furthermore, a concept will be developed that enables the steady state calculation with the help of a simple manual calculation. Worst-case scenarios for glazing and BIPV in façades will then be defined for a draft standard.

The experimental validation in WP 4 serves to validate the theoretical considerations and calibrate the different numerical models. For this purpose, an experimental programme is developed in this WP and selected test panels for glass structures in façades and BIPV are produced. A complete system, i.e., glazing including frame construction, is always tested. The tests are carried out in special test rigs in the accredited TestLab PV Modules of Fraunhofer ISE. The test results will then be evaluated and, if necessary, the numerical calculation models will be adapted accordingly.

In WP 5, a draft standard (façade glazing and BIPV) will be developed, based on the results from WP 1 to WP 4, and presented for discussion by representatives of ISM+D as well as Sunovation and Fraunhofer ISE in the corresponding standardisation committees.

5. Summary

The aim of the project is to investigate façade glazing and glass-glass PV modules (BIPV) in the building sector, which are subjected to thermally induced stresses by solar radiation, and to develop a draft standard based on the results of the investigations. On the one hand, a basic understanding of the relevant climatic and structural influencing parameters and their interrelationships is to be developed. In addition, the focus here is on the evaluation and provision of reliable, (freely) available meteorological data in Germany. On the other hand, approaches in the French standard (NF DTU 39 P3), which deals with the dimensioning of glass subjected to thermal stress and is applied in current construction practice "unofficially" throughout Europe for lack of an alternative, are examined more closely for orientation purposes.

Numerical simulations are being used to determine and qualitatively assess various influencing factors on the thermal stress calculation. As well, a generally accepted path should be identified to select the relevant meteorological data. Based on parameter studies, a simplified design procedure will be developed, which will be presented to various standardisation committees. The research project started in October 2020 and ends in September 2022.

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