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Climate Change Impacts on Photovoltaics, Solar Thermal Energy, Transparent Insulation and Energy Demand in the Building Sector

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Abstract

The impact of climate change on the energy demand of buildings is significantly higher than on solar technologies discussed in this paper (photovoltaic, solar thermal and transparent insulation material systems). On the one hand the heating energy demand will decrease by about 15% and on the other hand the cooling energy demand will increase by about 50%.

Among the solar energy conversion technologies, solar thermal systems will benefit the most, since they are positively influenced by increasing temperatures as well as increasing global radiation. The latter has a positive effect on photovoltaic (PV) systems either, which results even in a net profit considering the negatively influenced efficiency by higher air temperatures. The energy gains of transparent insulation material (TIM) systems are similar affected compared to PV systems. However, the useable thermal heat gains will only slightly increase due to shorter heating periods in the future.

Buildings are especially vulnerable regarding the climate change and should be adapted. Therefore different adaption strategies and options, which are easy to implement, are available and presented within this paper.

1. Introduction

On the one hand, climate change threatens buildings and infrastructure (roads, railways, etc.) by extreme weather events like floods and storms. On the other hand, there are also positive impacts on renewable energy systems utilizing solar energy (PV systems, solar thermal plants, TIM systems).

The impacts of climate change have been subjected to intensive research in the past. However, the focus has mostly been on agriculture and forestry; partly including the building sector (Weller et al., 2012; Voss and Künz, 2012; Holmes and Hacker, 2007; Frank, 2005).

The energy demand for buildings is significantly influenced by the changing climate conditions. Nevertheless, the knowledge of effects from the influence of temperature and global radiation on PV, solar thermal and TIM systems is rather moderate so far. The present paper defines the climatic impacts concerning the changing temperatures and global radiation on the energy demand of buildings as well as energy output of solar conversion technologies until the year 2035.

Due to the remarkable impact on buildings, easy to implement strategies are discussed in order to show possibilities towards the adaptation to future requirements of buildings concerning the climate change.

2. Climate data and calculation procedure

Depending on climate models, the increase of the yearly mean temperature is medium-term 1 K (until 2035) and long-term 3 K (until 2100), linked by an accumulation of hot summer days and tropical nights. In combination with rising global radiation a strong increase of the cooling energy demand will occur. In contrast to that, the demand for heating energy will decline following the predicted increase of the mean

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winter temperature. The predictions of increasing temperatures are reliable. However, the further changes in global radiation are subjected to uncertainties. According to the German Meteorological Service (DWD) there are no reliable information concerning the impact of climate change on global radiation. Other studies assume a minor increase. (Bernhofer et al., 2011)

The used mean test reference year (TRY) of the DWD for the calculation of the climate change effects represents the characteristic trend of weather conditions of a whole year. The analyzed TRY data sets are composed of real weather sections in such a way, that the mean values and scattering of the air temperature correlate with the long time monthly and seasonable mean values of each weather station. The reference values and weather sections for the TRY data sets are generated from measurement and observation data provided by the weather stations of the DWD between 1988 and 2007. TRY 2010 describes the typical year for the period from 1988 to 2007 and TRY 2035 characterizes the period from 2020 to 2050. Within this paper, the climate data for Potsdam (reference location for Germany) are used. According to the mentioned data, the presented results are based on the change in air temperature of 1.2 K for TRY 2035 from currently 9.5°C to 10.7°C as well as in global radiation of 3.2% from 1074 kWh/m² to 1109 kWh/m². (Project report DWD, 2011)

The heating, cooling and total energy demands of buildings as well as the energy gains of TIM systems are calculated according to the standards described in the Energy Saving Ordinance (EnEV) 2014. The balance study of the heating demand is carried out according to the monthly balance sheet procedure in (DIN V 4108-6: 2003-06, 2013) and for the cooling demand in accordance with (DIN V 18599, 2011). A four-storey, flat roofed office block without a cellar and with the basic size of 47.3 m x 12.5 m is taken as model building for the calculations according to (Klauß et. al, 2010). The outer volume, that has to be heated, is 7473.7 m^3 with a percentage of window area of 38.3% (Klauß et al., 2010). Typical usage behaviour for the office buildings is assumed. The insulation standards, as a thermal insulation composite system, and the heat transition coefficients of the reference building correspond to the EnEV 2014. The ventilation system, which is carried out as window ventilation, is assumed with a mean air exchange of 0.6 h^{-1}.

The calculations for photovoltaic and solar thermal systems are conducted according to a standard approach (Quaschning, 2011). The balance study of the PV energy yield takes into account particularly the influence of the cell temperatures. The nominal operating cell temperature is taken into consideration for estimating the self-heating of the cell. The expected cell temperature is calculated for any radiation and ambient temperature for a mean wind speed of 5 m/s. Moreover, a good rear ventilation of the PV modules is supposed. The balance study of the solar thermal systems is based on the efficiency procedure. Typical values are taken for the optical efficiency as well as the linear and quadratic heat loss coefficients, which are dependent on the type of collector (Quaschning, 2011). Concerning the forecast for the not covered collector, the data are reduced by the months, which do not belong to the swimming season (October till June), due to the fact that the collector is used only within the summer months.

3. Climate change impacts

3.1. Effects on photovoltaic systems

The effects of climate change impacts and their resulting changes in yield on PV systems are examined for crystalline and amorphous solar cells. The changes in yield compared to the reference period are plotted in Fig. 1. With a decrease of 0.3% in energy yield, which is approximately equivalent to the temperature coefficient, the impact of temperature is almost negligible.

Because of the direct correlation between energy yield and global radiation, the relative increase of global radiation is equal to the increase of PV energy yield. The cell temperature will in fact increase on an annual average by 0.1 K, but this small temperature rise does not lead to an appreciable change in yield.

The energy yield of photovoltaic systems declines slightly because of higher temperatures. However, due to the higher impact of global radiation, the overall energy output will increase for 2.9%.

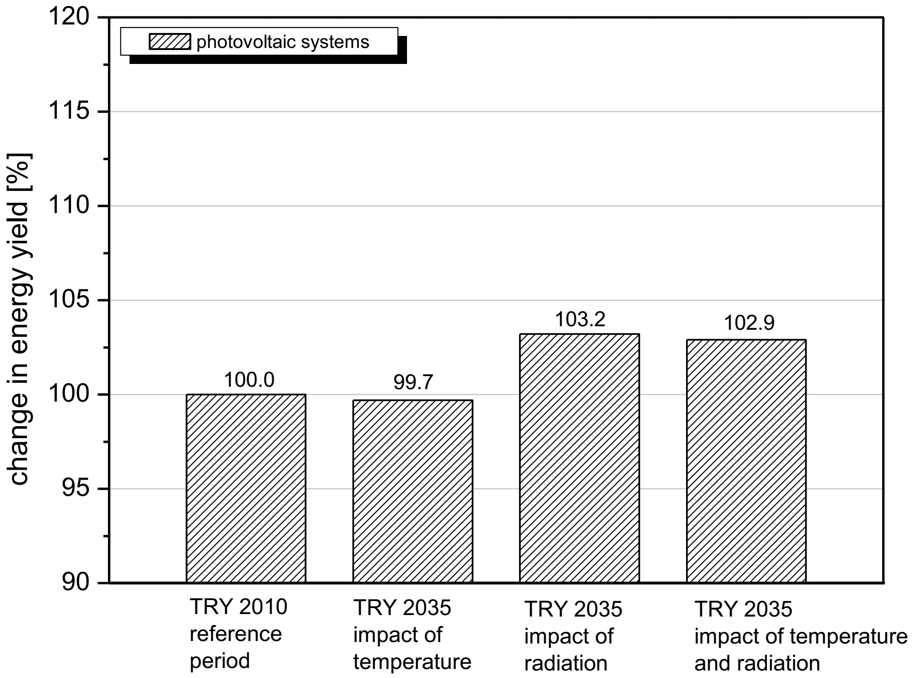

Fig. 1: Annual change in energy yield of photovoltaic dependent on climate parameters.

3.2. Effects on solar thermal systems

Solar thermal applications, e.g. vacuum tube collectors, flat plate collectors and not covered collectors, will benefit from the increasing global radiation and increasing temperatures. Therefore the overall output will increase considerably. The calculations taking into account the assumption that the solar energy is used totally. For example, this is the case, if the solar energy is used for water heating at low coverage rate; the values for this case are illustrated in Fig. 2.

The amount of energy yield increase varies depending on the collector type. An increase can be expected for vacuum tube collectors of 5% of annual energy yield and up to 17% for not covered collectors for the forecasted period in relation to the reference period. The rise of energy yield for not covered collectors is equally influenced by the increase of temperature and radiation. For vacuum tube and flat plate collectors the higher radiation is the main factor for the increased energy output supported by the higher air temperatures.

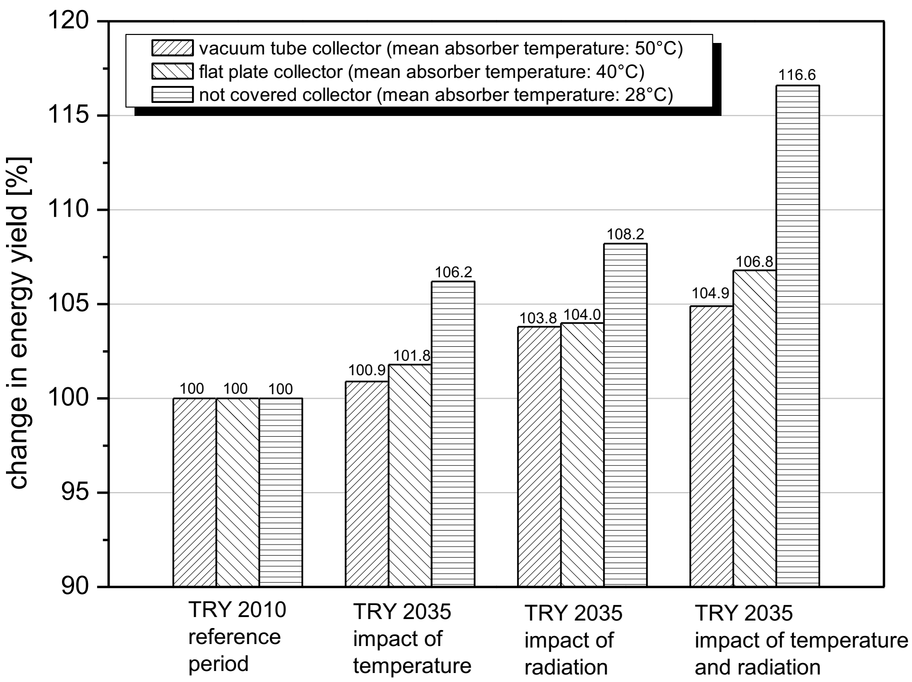

Fig. 2: Annual change in energy yield for different collector types dependent on climate parameters.

For other ways of using solar heat, e.g. solar systems for heating and hot water production, the benefit is influenced by the particular usage of the solar energy. The heating energy demand decreases by application for the heating support (see section 3.4), whereby the useable energy yields of solar collectors will decrease. However, the solar coverage rate will increase. Whereas in the case of employing the solar collectors for solar cooling, the absolute yield increases, due to rising temperatures which cause a longer period with cooling demand.

3.3. Effects on TIM systems

Another form of passive use of solar energy is the application of TIM systems. The advantages of TIM systems over opaque insulation are the utilisation of solar radiation for heating support and illumination of buildings in addition to the effect of heat insulation (low thermal conductivity).

Typical TIM systems are shown in Fig. 3. These systems offer an interesting option for the improvement of conventional solar thermal applications and for the utilization in the building sector. Additionally, they contribute to the increase of solar energy use, the reduction of costs and the resource conservation.

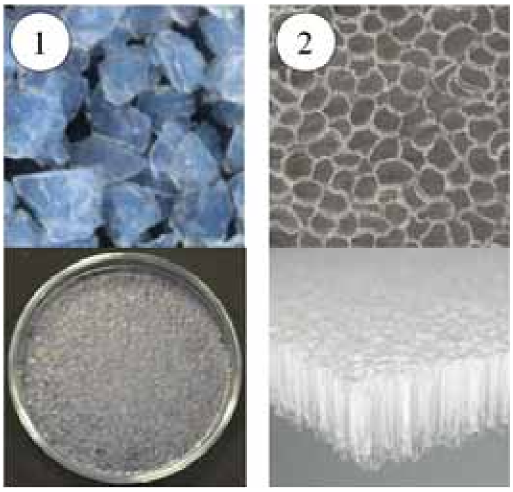

Fig. 3: Typical TIM: (1) Aerogel (source: Cabot Corporation), (2) PMMA capillary (source: OKALUX GmbH).

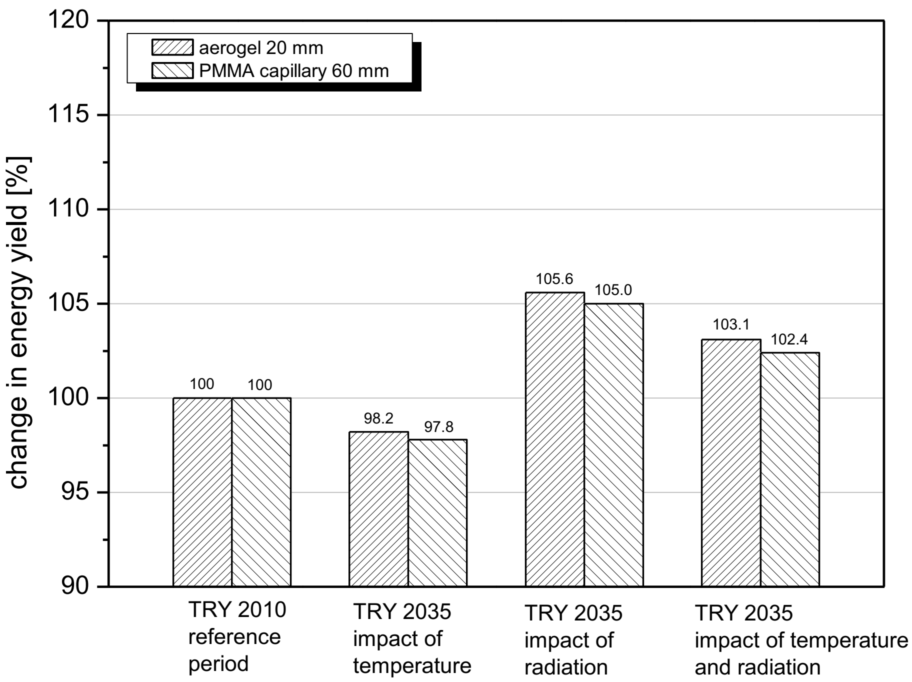

Fig. 4: Annual change in energy yield for different types of TIM dependent on climate parameters.

Despite of the mentioned benefits and proven functionality of TIM for more than 30 years, they usually hold a rather low market share. A recent TIM market study (Dorn et al., 2014) has shown that there is a high potential for the application of different TIM systems in the building sector. According to the study, some of the investigated TIM concepts show promising prospects of becoming market-ready soon.

The changes in yield are calculated for a typical residential building for the usable energy gains during the heating period. Fig. 4 shows the useable change in yield for different types of TIM dependent on various climate parameters.

The absolute energy gains are all positively affected and the TIM itself will profit from global radiation. The impact of increasing temperatures is slightly negative. These results are similar to those found for photovoltaic systems. Due to the higher impact of global radiation, the overall energy output will increase.

3.4. Effects on the energy demand of buildings

Concerning the effects on the energy demand of buildings, model calculations for a typical residential building with an indoor air temperature of 19°C and a cooling limit temperature of 25°C have been carried out. The impact of global radiation is low compared to the influence of temperature.

The heating energy demand will decrease by 14% until the year 2035, which is mainly due to the increase of the ambient temperature. On the contrary, the cooling energy demand will increase in the medium-term by 46%. The overall energy demand for heating and cooling will slightly decrease by 5%.

Regarding the energy demand in total values in the reference period for a typical residential building, the heating energy demand results in 68.7 kWh/m²a and the cooling energy demand in 12 kWh/m²a. The heating energy demand is 5.7 times higher than the cooling energy demand. This ratio will decrease to a factor of 3.4 for the TRY 2035. The consequences of an increasing cooling demand will result in retrofitting the buildings with air conditioning systems and accordingly rising costs for cooling (Lucas, 2014).

The consequence of a decreasing heating demand is a lower economic efficiency of insulation systems. The sun house concept, which maximizes the solar heat gains, will economically outperform the passive house concept, which minimizes the heat losses.

Foresighted, the importance of observing the demands for heat protection in the summer will become more and more necessary for new buildings and renovation of existing buildings. Adaption options for buildings will become essential due to the high climate impact on energy demand and with regard to the protective function of buildings.

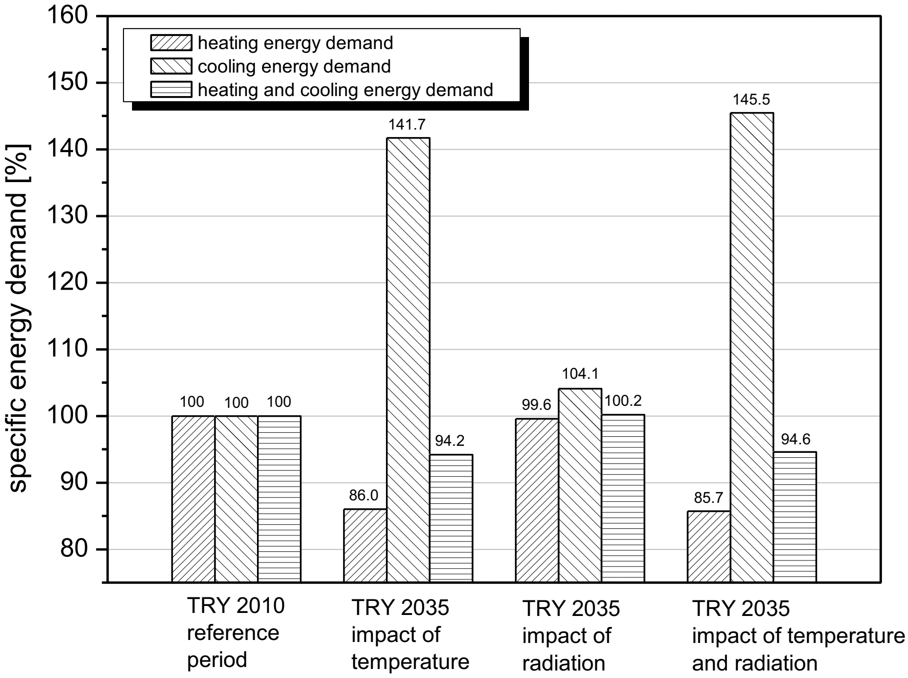

Fig. 5: Annual specific energy demand for residential buildings dependent on climate parameters.

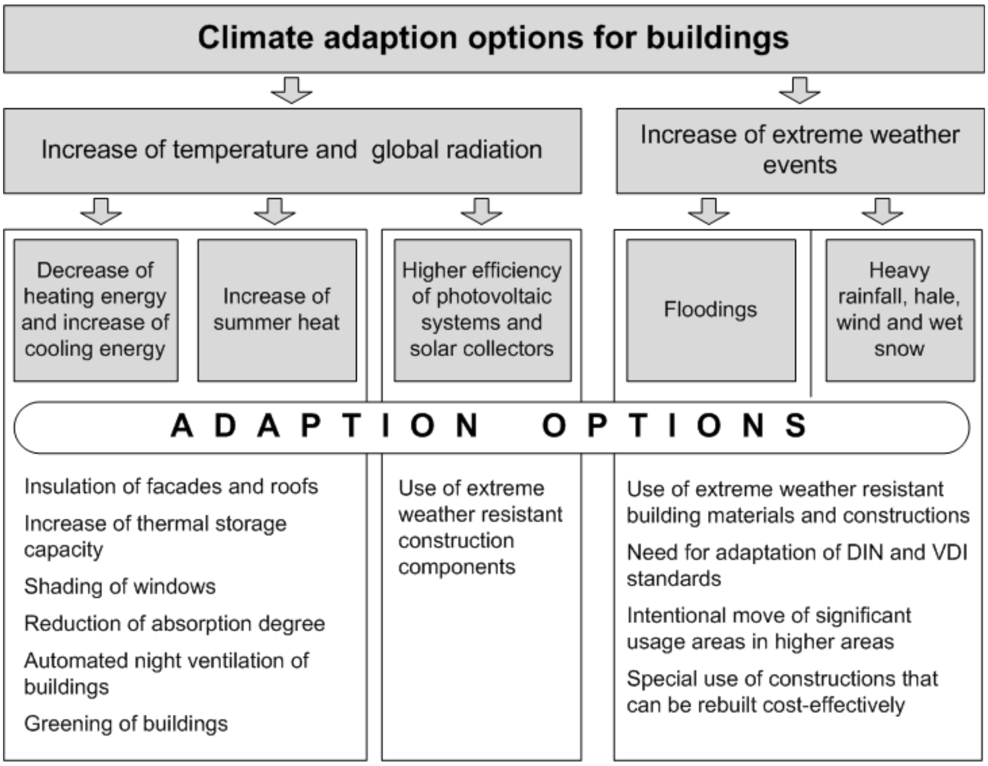

Fig. 6: Climate adaption options for buildings (Herrmann and Dorn, 2014)

Concerning the protective function, constructional modifications of buildings to the expected temperature and global radiation increase as well as protection measures are necessary. There are several prospects for new buildings or reconstruction and renovation of existing buildings which should be applied. The main adaption options are summarized in Fig. 6. With respect to the increase of extreme weather events, design modifications of buildings and technical systems will be required. Enhanced stability against heavy wind and proper leak tightness of buildings as well as the employment of moisture resistant and repellent construction materials will be recommended.

4. Summary

Tab. 1 summarizes the climate change parameters and the depending applications and gives an overview of the investigated data and values. The impact of climate change on the energy demand of buildings is much higher than on energy conversion technologies from renewable solar sources. The solar technologies are mainly influenced by global radiation, whereas the energy demand of buildings is foremost affected by temperature.

Among the solar energy conversion technologies, solar thermal systems will benefit the most, since they are positively influenced by increasing temperatures as well as increasing global radiation. The latter has a positive effect on PV systems either, which results in a net profit considering the negatively influenced efficiency by higher air temperatures. The energy gains of TIM systems are similar affected compared to PV.

In particular, buildings should be adapted to the climatic changes. Therefore a large number of adaption strategies and options, which are easy to implement, are available.

The presented approach is being further investigated within the projects "ANWan" (Inorganic-nonmetallic heat insulating materials with adjusted radiation properties), funded by the European Social Fund (ESF) and the project "REGKLAM" (Regional Climate Change Adaptation Programme for the Dresden Region), funded by the German Federal Ministry of Education and Research (BMBF).

Tab. 1: Overview of changes in output for solar technologies and the energy demand of building for TRY 2035.

	Impact of Air Temperature [%]	Impact of Global Radiation [%]	Accumulated Impact [%]
Changes in output for solar technologies			
Vacuum tube collector (solar thermal)	+0.9	+3.8	+4.9
Flat plate collector (solar thermal)	+1.8	+4.0	+6.8
Not covered collector (solar thermal)	+6.2	+8.2	+16.6
Transparent insulation materials	-2	+5	+3
Photovoltaic	-0.3	+3.2	+2.9
Changes of building energy demand			
Heating energy demand	-14	-0.4	-14.3
Cooling energy demand	+41.7	+4.1	+45.5
Heating and cooling energy demand	-5.8	+0.2	-5.4

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