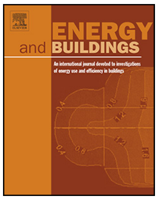
Energy and Buildings 105 (2015) 71–87

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild



Passive Houses for different climate zones

Jürgen Schnieders[a,*], Wolfgang Feist[a,b], Ludwig Rongen[c]

[a] *Passivhaus Institut, Rheinstraße 44/46, 64283 Darmstadt, Germany*
[b] *Universität Innsbruck, Institut für Konstruktion und Materialwissenschaften, Technikerstraße 19a, 6020 Innsbruck, Austria*
[c] *University of Applied Sciences, Erfurt and RoA Rongen Architekten, Propsteigasse 2, 41849 Wassenberg, Germany*

ARTICLE INFO

Article history:
Received 11 March 2015
Received in revised form 27 May 2015
Accepted 13 July 2015
Available online 20 July 2015

Keywords:
Passive House
Climate responsive building
Thermal comfort
Architecture
Energy efficiency

ABSTRACT

Passive Houses are buildings which provide comfortable indoor conditions at an extremely low heating and cooling load. The peak daily average heating and cooling loads are typically below 10 W/m^2 and annual useful energy demands are below 15 kW h/(m^2 a). The Passive House standard was originally developed in Germany. In this paper we show by hygro-thermal dynamic simulation that it is possible to realize residential Passive Houses in all of the world's relevant climate zones, represented here by Yekaterinburg, Tokyo, Shanghai, Las Vegas, Abu Dhabi, and Singapore. The window quality, insulation levels, and mechanical services all depend on the climate as well as on the building's shape and orientation. The resulting annual energy demand for space conditioning of the Passive Houses is 75 to 95% lower than that of a traditionally insulated building of the same geometry. In humid climates like Shanghai or Singapore, special attention must be paid to humidity aspects. In climates which are hot and humid all year long, the total useful energy demand for sensible and latent cooling may exceed 70 kW h/(m^2 a) even in a Passive House. Finally, it is shown that the architectural quality is not compromised by the Passive House requirements.

1. Introduction

The first "Passive House" was built in 1991 in Darmstadt-Kranichstein, Germany. It was the result of a research project that aimed at minimizing the total energy demand of the dwelling by optimizing the efficiency of all components, including DHW, auxiliary electricity, appliances and lighting. Concerning the building itself, the focus was on passive strategies such as insulation, high-quality windows, airtightness, ventilation heat recovery, and the avoidance of thermal bridges.

At levels of high user satisfaction, the following energy consumption figures[1] were measured [1]:

- Annual space heating consumption: 11.9 kW h/(m^2 a).
- Hot water: 6.1 kW h/(m^2 a).
- Gas for cooking: 2.6 kW h/(m^2 a).
- Total electricity consumption, including all household applications: 11.2 kW h/(m^2 a).

In particular, the building used less than 10% of the heating energy of a new building complying to the then current German building code.

From this first example, the Passive House building standard was further elaborated. Follow-up projects in Germany and similar climates demonstrated that Passive Houses generally make do with 80 to 90% less heating energy than conventional new buildings, at additional building costs of 5 to 10% [2,3].

The low additional cost is key to Passive House projects being more than just isolated beacons. It is due to the fact that mechanical systems can be significantly simplified because of the high efficiency of the building envelope. One proven possibility is to distribute space heating by means of the airflow required for good indoor air quality, without radiators and pipes, and without recirculated air with its high levels of auxiliary electricity demand, space requirements, noise, and draft risk. This is the functional definition of the Passive House: The building can be heated, cooled and dehumidified simply by conditioning the supply air. It was shown that this is possible up to a peak heating or sensible cooling power of 10 W/m^2 [4,5].

---

* Corresponding author. Tel.: +49 6151 826990.
E-mail address: juergen.schnieders@passiv.de (J. Schnieders).

[1] All characteristic values in this paper refer to the living area, i.e. the sum of the net floor areas of all rooms within the thermal envelope, excluding the surfaces of internal and external walls or staircases. This reference area is significantly smaller than the gross floor area.

http://dx.doi.org/10.1016/j.enbuild.2015.07.032
0378-7788/

The basic principle of the Passive House is to minimize all heat flows at and within the building envelope. Passive Houses also make use of passive solar gains if available, but they can just as well be realised if the building site has poor access to solar radiation. They are thus not necessarily “passive solar houses.”

The fundamentals of planning Passive Houses in practice have been summarized e.g. in [6] and [7]. The standard design tool is the Passive House Planning Package (PHPP, [8]). The energy perfomance predicted by the PHPP is in good agreement with measured values, as the evaluation of monitoring campaigns has shown (cf. e.g. [2,9–13]).

Building to the requirements of the Passive House standard is becoming more and more popular. By the end of 2014, more than 1 million square meters of useful floor area in Passive Houses had undergone the certification scheme that was set up by the Passive House Institute in Darmstadt, Germany [14].

Some buildings that follow Passive House principles and use the respective components have also been built in climates that differ considerably from those of Germany or Austria. As of Dec 31, 2014, the data base in [15] lists 91 realised projects outside of Europe, 47 of which are situated in the US. Many of these projects are also described in greater detail in the proceedings of the International Passive House Conferences [16].

The present paper is based on a detailed study about Passive Houses for different climate zones [5] and a later extension for tropical climates [7]. It aims at providing a consistent theoretical basis for the transfer of the Passive House concept to residential buildings in climates that differ fundamentally from central Europe. For identical building geometries in six very different climates we will show by means of hygrothermal dynamic building simulation what it takes to realize a Passive House, as judged by the functional criterion of supply air climatization. We will emphasize some particular aspects of each climate and report the resulting energy demands. Furthermore, we will demonstrate that the efficiency of a Passive House does not need to compromise architectural freedom.

2. Simulations

2.1. Climates

Locations were selected according to different aspects. One of the study’s objectives was to determine in what parts of the world Passive Houses can be built at all. We therefore preferred relatively demanding climates. Second, the locations were selected for importance, i.e. the climates should be representative for a large geographic area and, simultaneously, should cover regions where high construction rates are expected over the next few decades. Finally, the availability of reliable climate data for dynamic building simulations was a criterion.

Results for the following 6 climates will be presented:

- 01—Yekaterinburg, a cold climate. Ambient temperatures drop as low as −30 °C, but solar radiation levels are higher than in Germany. A climate data set from the IWEC collection [17], Category 1 (“files can be used with confidence”), was used.
- 02—Tokyo, a subtropcial warm climate. Winters are mild, with frost occuring only occasionally. Summers are warm and humid. An IWEC Category 2 data file (“use with caution”) for Hyakuri airport, approximately 100 km northeast of downtown Tokyo and about 3.5 K colder, was the best possible choice.
- 03—Shanghai, also a subtropical warm climate. Following a plausibility check of all available data, IWEC Category 2 data for a location in the southern part of the city were chosen.
- 04—Las Vegas, a hot and dry climate with great temperature differences of 15 K during a typical day. TMY3 data from McCarran Airport in the southern part of the city were used.
- 05—Abu Dhabi, a hot and humid climate. Peak summer temperatures reach 45 °C, solar radiation levels are very high, humidity ratios get as high as 20 g/kg. IWEC Category 1 data from Abu Dhabi airport were used. The weather station is situated approximately 30 km from the coastline, but only 5 km from the Al-Raha Bay.
- 06—Singapore, a tropical climate. Ambient conditions are fairly constant throughout the year, with temperatures around 28 °C, small daily fluctuations, and humidity ratios between 18 and 20 g/kg. An IWEC Category 2 data set from the townward side of the Changi airport appeared to be the best choice.

Table 1 summarizes some relevant properties of the climates. Figs. 1–6 further illustrate their characteristics. For each location the figures show the dry bulb temperatures in winter and summer, a third diagram displays the humidity ratio during the warmest months. Apart from the hourly values, a running mean for a period of one week is shown. In 06—Singapore there is no distinct winter or summer season, so we chose a slightly different representation.

Table 1
Some properties of the climates.

	01—Yekaterinburg	02—Tokyo	03—Shanghai	04—Las Vegas	05—Abu Dhabi	06—Singapore
Latitude	56.8°	36.2°	31.4°	35.7°	24.4°	1.4°
Longitude	60.6°	140.4°	121.4°	−115.2°	54.7°	104.0°
Elevation	237 m	35 m	7 m	648 m	27 m	16 m
Annual average temperature	2.4 °C	13.1 °C	16.3 °C	19.8 °C	27.1 °C	27.5 °C
Max. daily average temperature	25.1 °C	28.6 °C	33.3 °C	37.0 °C	38.8 °C	30.2 °C
Average temperature Jun–Sep	14.8 °C	21.7 °C	25.9 °C	30.6 °C	33.7 °C	27.8 °C
Average daily temperature variation (max–min) Jun–Sep	9.1 K	7.5 K	6.2 K	14.6 K	13.3 K	5.7 K
Average humidity ratio Jun–Sep	7.8 g/kg	14.3 g/kg	17.2 g/kg	5.6 g/kg	17.2 g/kg	19.3 g/kg
Solar horizontal Jun–Sep	141 kW h/(m^2 mon)	128 kW h/(m^2 mon)	131 kW h/(m^2 mon)	225 kW h/(m^2 mon)	221 kW h/(m^2 mon)	139 kW h/(m^2 mon)
Solar South Jun–Sep	88 kW h/(m^2 mon)	63 kW h/(m^2 mon)	55 kW h/(m^2 mon)	85 kW h/(m^2 mon)	61 kW h/(m^2 mon)	54 kW h/(m^2 mon)
Solar E/W Jun–Sep	72 kW h/(m^2 mon)	63 kW h/(m^2 mon)	64 kW h/(m^2 mon)	115 kW h/(m^2 mon)	91 kW h/(m^2 mon)	68 kW h/(m^2 mon)
Min. daily average temperature	−26.3 °C	−2.0 °C	−0.5 °C	1.5 °C	15.5 °C	24.4 °C
Average temperature Nov–Feb	−11.0 °C	4.9 °C	7.3 °C	9.6 °C	20.6 °C	26.7 °C
Average daily temperature variation (max–min) Nov–Feb	7.7 K	12.1 K	6.8 K	11.6 K	11.5 K	5.5 K
Average humidity ratio Nov–Feb	1.5 g/kg	4.1 g/kg	5.0 g/kg	2.8 g/kg	10.1 g/kg	18.8 g/kg
Solar horizontal Nov–Feb	21 kW h/(m^2 mon)	76 kW h/(m^2 mon)	70 kW h/(m^2 mon)	98 kW h/(m^2 mon)	135 kW h/(m^2 mon)	134 kW h/(m^2 mon)
Solar South Nov–Feb	33 kW h/(m^2 mon)	88 kW h/(m^2 mon)	65 kW h/(m^2 mon)	134 kW h/(m^2 mon)	131 kW h/(m^2 mon)	72 kW h/(m^2 mon)
Solar E/W Nov–Feb	13 kW h/(m^2 mon)	40 kW h/(m^2 mon)	34 kW h/(m^2 mon)	59 kW h/(m^2 mon)	66 kW h/(m^2 mon)	68 kW h/(m^2 mon)

All temperatures are dry bulb air temperatures.