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Entry

Reducing CO_2 in Passivhaus-Adapted Affordable Tropical Homes

Karl Wagner

The President's Office, Technical University of Applied Sciences Rosenheim, D-83043 Rosenheim, Germany; karl.wagner@th-rosenheim.de

Definition: On average, houses including those in the tropics are responsible for almost 39% of the global carbon emission caused by non-renewables, first and foremost by fuel. Looking at the worldwide map of residential buildings' contribution compared with commercial, the worldwide national maximum of 33.5% CO_2 of housing is caused by residential buildings in Uzbekistan. In an overwhelming number of most countries, their values are significantly lower, due to comparably lower energy demand than commercial buildings and because affordable homes increasingly use small PV to cater for their own basic needs. However, with the rising temperature and a likewise growing imperative to cool homes from about 30 °C onwards basically by split-unit air conditioners, the residential houses' portion of CO_2-emission might dramatically increase to survive such more common hot periods in the future. In combination with air conditioners needing some airtightness, the first purpose of this entry is to show that bv 2050 in tropical regions, there will be no alternative to relatively airtight houses if the temperatures rise at the present speed. This is one alternative to an uncontrollable and life-threatening migration of millions of people to cooler but still livable regions in 2050. To trigger necessary changes toward homes that can better avert the heat, using the method of qualitative comparative content analysis, passive houses (PH) have emerged as adaptations to the tropical climate. Therefore, the second purpose of this in-depth study with the perspective of social science, is to reveal a comparative closer qualitative look at the tropicalized PH-approach. It is probably the most civilized building energy-saving strategy on the planet and can systematically keep the threatening increasing heat outside. However, before utilizing the concept, herein need to investigate why PH-technology as a whole concept with all its modules discussed earlier has been very slow to "go South" into the tropical region (the original PH will be referred to as "PH1"). The reason is that some qualitative differences of the more affordable and more simplistic tropicalized "PH2" make it easier and more realistic to penetrate the market, without letting go meaningful R&D-insights of PH1. As a probably facilitating future solution, the result is the triple-tabled option to utilise more synergies between the usually closed PH1 and the more open and flexibly naturally ventilated PH2. Unlike the PH-platform, ZEMCH is a related concept which tries to cater specifically to the significantly growing market for lower-income homes to go for carbonless energy. The conclusion is that scaling for residential buildings as mass products using passive house technology in combination with ZEMCH could turn out to become an important topic. It comprises the question in how far low or no carbon affordable homes based on the PH-concept in combination with ZEMCH-applications also may come into play as standard and to help mother Earth's struggle for survival.

Keywords: climate change; Passivhaus; ZEMCH; affordable housing; synergies

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Citation: Wagner, K. Reducing CO_2 in Passivhaus-Adapted Affordable Tropical Homes. *Encyclopedia* **2023**, *3*, 168–181. https://doi.org/10.3390/encyclopedia3010012

Academic Editors: Masa Noguchi, Antonio Frattari, Carlos Torres Formoso, Haşim Altan, John Odhiambo Onyango, Jun-Tae Kim, Kheira Anissa Tabet Aoul, Mehdi Amirkhani, Sara Jane Wilkinson, Shaila Bantanur and Raffaele Barretta

Received: 20 July 2022
Revised: 22 September 2022
Accepted: 3 October 2022
Published: 26 January 2023

1. Two Different Passive House Concepts (PH1 vs. PH2) and Methodology

In building science, and logically in everyday life, a building anywhere on the globe, is an "environmental separator between inside and outside" [1]. Green buildings attempt to reduce carbon against the hotter years to come. They firm up under different concepts and strategies, such as low and zero energy houses, zero energy buildings, nearly zero-emission building (NZEB), zero-emission buildings to name a few prominent ones. Some of these green building concepts are to be implemented in the EU between 2020 and 2030.

Among these strategies, worldwide, the most energy efficient concept is the Passivhaus. It will be using and tabling two slightly differing passive house concepts, PH1 and PH2, applying three comparative content analyses as methodology that is widely used in social science. In the tradition of the sociologists Emile Durkheim and Max Weber, this is a kind of a bird's-eye view perspective and method of comparing the two contents with the "idea of uncovering and discovering new ideas about them" [2].

Applying this methodology, it seems consensual that passive basically means that the indoor climate is separated by the building envelope against an unhealthy or uncomfortable outdoor climate for humans. This counts also vice versa: If the outdoor conditions are more comfortable and healthier compared with indoor, why not open windows and perhaps even doors?

However, based on the methodology of comparative content analysis, "passive house technology" generated by concepts in building science has two different meanings. From a social science perspective, the content analysis of "passive" will be used in the tradition of relationism and phenomenology as the "discipline of phenomenology that may be defined initially as the entry of structures of experience, or consciousness" [3]. Literally, phenomenology is the entry of everyday life "phenomena," which states that different actors even like architects or building scientists might have different perceptions. This will depend on how science teaches to experience passive as part of the own social community and how different perspectives can work together. Accordingly, phenomenology describes and analyses the appearances of things, as they appear in experience, "the study of phenomena (= things that exist and can be seen, felt, tasted, etc.) and how experience them [4].

Hence, based on qualitative phenomenological studies, our first look will be at PH from five different perspectives; out of four principal ways how to build homes, looking at mainstream and three passive strategies, and within two concepts for passive houses:

1. **Conventional house**. Nothing is optimized. Buildings are just cheap and fast focusing only on fast ROIs. These houses stack the heat. Its type A works with relatively energy saving fans (50%), type B with A/C, at least in the master sleeping room. Type B compared to type A is characterized by a high carbon footprint.
2. **House with element(s) of passive technology**. Architects try to educate people to use more passive modules based on natural ventilation, which as a minimum requirement just means opening windows all day and night long to save CO_2: "The most important passive design strategy in the tropics is to open up houses as much as possible, even during the heat of the day, to achieve maximum cross ventilation and convective air flow" [5]. This is a common behaviour for most households in warm and hot conditions like in the tropics.
3. **PH1,** as presented below, was developed and marketed from the cold hemisphere (Central Europe, Sweden, USA/ Utah), following their credo with meticulously defined necessities of insulation and airtightness with software like PHPP which restricts the user's calculation to a clear standard saves enormously carbon.
4. **PH2** resembles PH1 but looks in depth at tropical adaptations. It is a combination of daytime closed and nighttime open windows, which is unsuitable for PH1 under tropical conditions of high temperature and absolute => relative humidity. It can lead to more RH if is it not controlled, and it may lead to higher "adaptive" temperatures of occupants. Therefore, tropically adapted Passive Houses (PH2) can accept higher temperatures. with set points up to 28 °C and any humidity. Hence, it will be seen more energy saving than the conventional PH1-standards with their maximum allowable temperature of 25 °C and 60% relative humidity integrated in the software tool PHPP.
5. In addition, the **ZEMCH** network products are not a derivation of 3 or 4 but could be closely related to one of them, making use of passive technology. ZEMCH is not restricted to its features. Its application might also be more related to nearly zero-emission building (NZEB).

Option 1 is still common but is not a not subject in this contribution, as looking towards more carbon-free solutions. Both 1 and 2 have no radar for real passive sustainability, as the house remains hot. Option 2 is just patchwork and does not lead to CO_2 saving targets like the PH 1 and 2, along with ZEMCH buildings.

Before applying phenomenology as a tool to compare the two remaining Passivhaus concepts (1) in the colder hemisphere and (2) its potential in the tropics, looking at different passive strategies to achieve more conducive thermal comfort. In the decades of approaching global warming catastrophes, this can be seen as a "higher" reason to assist to reduce climate change in the building sector. In the case of passive technology and how to achieve thermal comfort for occupants, it is about the (non-) interaction of two basically latent controversial standpoints passive technology and the renowned PH1. (Especially PH2 as a potential further development of the PH with ZEMCH which stresses on scalable affordable mass homes will follow later).

Comparing 2. Passive technology and 3. Passive Houses from the phenomenologist's perspective are like asking two building scientists who more unconsciously but inadvertently refused talking about the generic meaning of "passive" to each other. Decades to communicate and exchange ideas have passed by since the word ever occurred, probably independently, in tropical and colder climate origins.

The first one promoting passive technology will be called the "classical tropical" type approach that even at certain times maximises natural ventilation and the second one "passive" PH1 using the building envelope as a basic fortress against the heat. At certain "hot" times, air conditioning and in less hot cases cool-water-based cooling ceilings or walls are needed, protected by a closed-up building envelope. In this entry, by qualitative content analysis, the second meaning of passive related to PH1 and PH2, and, by the applied analysis will be pursued, try to reconcile both.

Since 1991, the State of the Art Passivhaus in the traces of type PH1 follows five principles. Instead of heat recovery, compulsory cooling recovery is suggested for tropical buildings and those in the colder hemisphere during the hot season. In cold regions like Iceland, back in the Middle Ages, dwellers started to build passive-like turf houses after wood became scarce [6]. It requires artificial cooling in residential buildings under hot conditions usually performed by air conditioners as clear separator between inside and outside climate was laid out around 1980 in Utah/USA by its fundamental DIYS-inventor, Amory Lovins [7]. Wolfgang Feist (formerly Institute for Housing and the Environment, /Institut Wohnen und Umwelt Darmstadt/Germany) and Bo Adamson (Lund University, Lund/Sweden) introduced and further developed the concept in Europe. The emerging "Passive House standard" originated from a conversation in May 1988 between Adamson and Feist, but was much more than a new label for a green building. Its founders agreed on strict criteria to make it the most radical "green" version of a thermally comfortable low energy house. Apart from any consumable energy, it is defined by extremely low heating and, likewise if applicable, cooling demand [8]. It results in the fact that (apart from other energy efficient features) necessary warmth or coolness can be implemented primarily by the supply of an (active) mechanical ventilation system. Adamson's idea of mechanical instead of sometimes not working natural ventilation was first rejected by Feist but was soon understood as a necessity to make PHs a reality with basic airtightness plus outside air if necessary [9]. When 90% less energy was consumed in the world's first passive residential house at Kranichstein/Darmstadt in 1991, experts said to Feist that it must be an error, but obviously it was not: Even by 2021, 30 years after the first building was set up, no decrease in terms of this 90% less energy performance could yet be reported, with still low maintenance efforts [10].

2. The Passive House Approach and an Outline for Its Dedicated Tropical Adaptation Model

The generic five elements and benchmarks of a Passivhaus (PH1) are well documented both in literature and video clips: airtightness, insulation, avoidance or thermal bridges, Passivhaus windows, and ventilation with heat recovery [11–14].

In addition, a tropically adapted holistic passive house (PH2) concept shaping up since 2016, has been elaborated on with the initiative of and collaboration of a ventilation developer and an international architecture Passive House IPHA firm from Munich/Germany. Basically, tropical buildings should adhere to a new entirety (totality) consisting of the following seven or eight revised core modules of five real passive and two or three active elements as well. The East, West, South or North "orientation" in the orange box is general, whereas the 4 elements for "passive" Insulation are indicated in the green boxes. The 3 modules for ventilation and (de-)humidification (blue boxes) point to "active" elements of a Passivhaus [15]. The modules are highlighted in the following Figure 1:

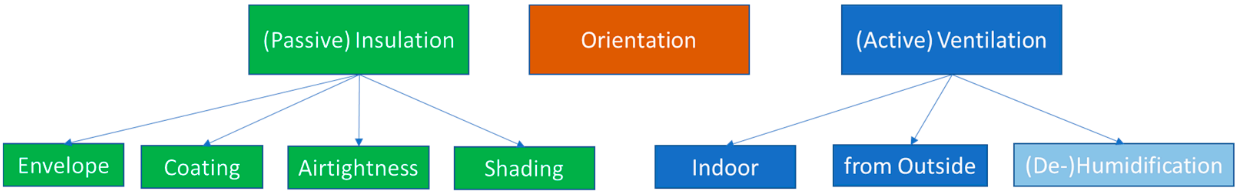

Figure 1. Output Pillars of the Passivhaus for a tropical Building.

These core modules and benchmarks of a tropical passive house are described below. They add on adapted value to the existing five of a general passive house. "Orientation" is the source for everything that happens in terms of solar radiation (the positioning is less meant for the hardly 365 days predictable natural ventilation). As shown in Figure 1, "De-"humidification carries a question mark because whether it is ultimately necessary for affordable tropical mass homes have to be discussed, which are in the focus of this entry [16]. According to discussions one month ago with an IPHA member, it was conceded that no humidification may not necessarily create mould inside the house in case of natural ventilation, when daytime hotness offsets nighttime humidity (leading to what we refer to PH 2).

In a first step of the comparison, it can be now narrowed down the scope and Table the seven or eight tropical modules as exhibited in Figure 1 above. In a second step in Table 1 below, justifying the deriving thoughts on marketability is needed. In the light of climate change with requirements toward affordability and marketability, the criteria do not necessarily coincide with the universal passive house PH1 principles [17]. Table 1 highlights the differences between the conventional Passive House (1) and the detected or derived specifications of PH2:

Table 1. Details of the Adjusted Seven to Eight Modules and Benchmarks of a Tropically Adapted Passive House (PH2).

No	Element	Description
1.	 Building Orientation	Depending on the geographical location, the orientation of a planned building will be optimised by minimising or -if possible- excluding solar exposure through the windows (passive). On tropical islands or coastlines like Penang / Malaysia or Baranquilla/Colombia, the most common wind direction can determine the building's orientation. However, the wind's orientation will be exposed to seasonal fluctuations. Therefore, relying on the cool night time natural breeze by opening the windows, is not sufficient to provide indoor tropical thermal comfort.

Table 1. *Cont.*

No	Element	Description
2.	Building Envelope	Insulation of the building envlope (wall, roof, minimising thermal bridges and low-e glazing) will reduce the exterior heat infusion. At the same time, the desired ambient tropical USL temperature inside the dwelling will be pursued, as long as the occupants are inside. In the tropics, experiments have proof-cased that multiple layered glazing is not necessary, as the thermal difference between given outdoor and yielded indoor temperature is much lower than for cold countries. Tropical countries better invest into coating, less convective window frames with heat brakes and into shading (no. 5) (passive).
3.	Basic Airtightness	Like in countries of the colder hemisphere, a basic airtight tropical building envelope with minimized thermal air bridges will prevent the infiltration of "default" too hot, sometimes too humid and polluted air, whilst maintaining the desired indoor temperature. However, airtightness in shaded tropical buildings is not a radical must as in countries with seasonally huge differences between the outside and inside temperature. (Formula in the PHPP: Airtightness (AT) < 0.6 /h at a pressure difference compared inside to the outside of 50 pascal). In tropical adaptations, the concept also includes filtered mechanical exterior ventilation especially during the nighttime (passive/active).
4.	Reflective Coating	Especially in tropical buildings, outer surfaces of the building envelope like exterior walls and roofs, are coated with brighter colours which reflect solar radiation to further reduce heat gains into the building. Off-white or light yellow contribute to lower heat gains through the entire building envelope and the windows (passive). Perhaps an affordable house of the future has white walls and dark solar panels as additional sun protection in an angle of about 30° to optimise attic cross ventilation on the roof.
5.	Shading	Recently also adopted by northern hemisphere passive houses, external shading tools (fixed or movable) will stop direct solar gains inside the building or the room through the windows. Different compared to cold country passive standards which have been adapted to the tropics, reducing the heat gain by shading is not about double- or triple-glazed sun protection windows. The reason is that it is considered as not necessary for the small temperature difference between the real shaded outside and the desired inside temperature (passive with a bit of smart active for flexibly opening the shades to let natural light inside the building in case direct radiation is absent). Typical 30–32 °C outside (shaded) temperature does not justify double or even triple glazing if the set point is 26–28 °C. In buildings with a high window-wall ratio where the unshaded sun hits with 55 °C survival without intense usage of air conditioners is impossible.
6.	Dehumidification?	Allowing temporary humidity or not can turn into a very controversial question. That is why the author assigned it with a question mark for tropical countries: Considered as a must or an option for enclosed buildings or rooms, it is not applicable for the huge majority of naturally ventilated ones where neither outside temperature nor humidity is stoppable. Nocturnal typical relative humidities of 85% and above will not automatically make buildings grow mould. Basically, the issue of high humdity and its consequences is balanced out by the logical credo "what gets wet, must get dry again [18]". Hence, if wetness intrudes during the night time, it might dissipate by the lower humidity at least in the growing urban areas catalysed by the "heat island effect" [19]. And, prior to further investigation the question may be allowed: why have old highrises built in the 1970s and 1980s which were fully naturally ventilated not all become victims of mould?
7.	Efficient Outside Air Cross-Ventilation	A constant supply of fresh air from outside keeps the indoor environment healthy—if it is professionally drawn out again by an exhaust fan or at least an empty hollow [20]. This is the real natural ventilation, which is based on mechanical ventilation, which would not happen, if only the windows are open. If mechanical air supply fans are used, however, in polluted areas the outside air must be filtered. Not like in conventional Passive Houses (PH1) especially during night times, in tropical highlands the air does not have to be pre-cooled to produce also cool air before penetrating from outside. The ventilation in the tropical highlands is different to the colder hemisphere: it maximises the air stream when the temperature falls below the upper borderline of thermal comfort or cooler outside (active).

Table 1. *Cont.*

No	Element	Description
8.	 Internal Air Movement	Stand-alone indoor ventilators as catalysts for 7. are not obsolete in a tropical passive house which is proposed here. On the contrary, internal air movement devices get two new meanings for residential and commercial buildings: Type 1: Different sorts of fans (stand, table or ceiling) are conceptualised of as systems, preferably in combination with 7. They permit higher set-point temperatures for tropically adapted cooling systems while providing individualised thermal comfort for occupants by blowing "personalised" air onto the occupants, hereby reducing the ambiently felt temperature. Type 2: Internal air re-produced by the A/C compressor which should be minimized, as the cooling pushes in with 11 °C. This is uncomfortable like draughts are looked upon in the colder hemisphere (active).

Non-tropicalised passive house (PH1) concepts have been adopted in estimated almost 65,000 buildings (2–5% of them certified, i.e., 95–98% are non-certified applications in all different climatic areas including 7–9 certified implementations in tropical countries). The answer depends on where the line between tropical and subtropical climate zones are drawn. Either following mainstream determining "tropical zone or not" by the latitude, or looking into climatic details as Köppen and Geiger did [21]. The following Figure 2 will scrutinize their locations.

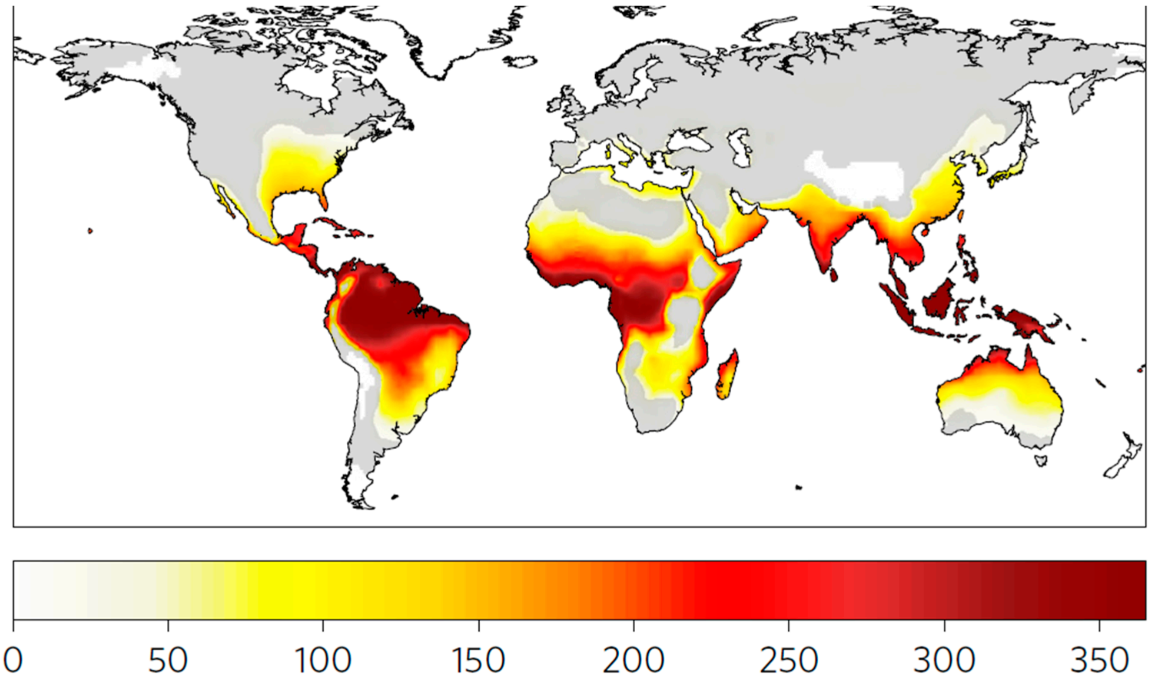

Figure 2. Global risk of deadly heat days with a Scale of annual overheated Days forecasting Climate Change in 2050 where residents need to stay in cooled areas to survive at least during the daytime. Adapted with permission from reference [22], Copyright 2017 Springer Nature.

However, talking about future protection against global warming by innovative building technology like the PH, this is where its potentially most important application of the future is found: the region where most people live. The tropical belt in 2020 was home to about 40% of the world's population, and will host more than 50% of the world population by the late 2030s or early 2040s [22]. As in the tropics it is nowhere too cold to survive, but too hot at some places, most low- and middle-income people do neither cool, but naturally use the open door and windows style, if the tropics can sustain as a place to live, which is becoming questionable [23]. This is indicated by the red and dark red regions on the globe whereby almost all tropical regions are in the danger zone of 250–365 heat-affected days in 2050:

Hence, like shown in Figure 2, the researchers around Mora described the devastating exacerbating consequences of global warming until 2050. Counting the days with temperatures of 35 °C and above, according to their global map, almost everywhere around the tropical belt the temperature is going to be deadly and would include a never-known exodus of homeless populations to colder areas [23] - unless new building codes especially for affordable houses can be found to at least (!) delay parts of the catastrophic development.

Before taking up how to go about these severe consequences, utilizing natural air is still much more carbon-free than sealed buildings mainly cooled with air cons [24]. This is practiced in the colder countries of the northern hemisphere, where in some locations carbon-triggering heating is still necessary for a couple of months or in some places almost the whole year long. Hence, most cooling is more expensive than heating, and times will change toward this direction: the hotter the climate gets, and the more people need to adopt to close them up and use air conditions, the more dreadful the emissions. This vicious circle that started long ago with worldwide sales of four AC units per minute [25] states clearly it is high time to talk about viable alternatives, if still possible.

Before shedding light on why alternative tropical passive house of the future will unlikely follow the mandatory global trend standards, Table 2 demonstrates likely differences between its cold hemisphere features and those emerging tropical ones:

Table 2. Summary: 7 Differences of PH1 (any colder hemisphere) compared with Tropical Holistic Passive Technology (PH2).

Element	Sustainable Passive Homes in Moderate Cold Hemisphere (Based on PH1-Benchmarks)	Equatorial Tropical Sustainable Homes (with Some Modifications also Counts for ZEMCH)
(1) Glazing/Façade	Triple Glazing as standard to prevent coldness at a lambda T of up to −30 °C (and colder in some Northern areas)	Ideal Types: A. No Triple Glazing. Double layer coated on window pane 2 to prevent heat transfer + Film (if sunlit) with UPVC-frame. Double layer can also be put onto the frame by any experienced carpenter B. Single coated with UPVC-frame (if fully shaded to avoid convection of 32–36 °C of common outside temperature through the windows panes): but windows do not explicitly appear C. Windows-wall ratio best not exceeding 30%
(2) Insulation	Different layers of up to above 40 cm exterior walls thickness	Lightweight concrete Walls calculated e.g., for 5° latitude sufficient as <22 cm to insulate or best using natural fibre (blow, resilient and construction board). Replacing 10 cm thick conventional walls.
(3) Green Retrofitting	Energy efficient solutions	Cladding, shutter, overhang roof, outside blinds, IAQ
(4) PV	Mono/Poly Crystalloid producing optimum yield	Higher performances by more expensive thin film technology. Parity Grid forecast e.g., for Malaysia in 2026/27 [26].
(5) Solar Thermal	warm water supply, link to PV	Warm water supply just for wealthier households with a certain market penetration compared to "red" water heaters
(6) Heat Gain e.g., by people/personal computer in small size rooms	Functional more or less during all seasons, except during hot summer days	Always dysfunctional, internal CO_2 and VOCs rising
(7) Cooling [27]	During hot summer days. e.g., terracotta tiles in conjunction with maximum nighttime opening. Geothermal—cold water as slab cooling. A few fans against the slightly increasing numbers of A/C	Smart conventional A/C (or inverter?), outside nighttime "flush" ventilation in non-coastal and certain areas in low altitude, rare cooling ceilings. Utilisation of wells with temperatures of 25 °C in 10 m depth around the equator for ceiling or wall cooling – rain or well water or heat exchanger, VRF-ventilation systems

3. Difficulties Any Passive House Concept Faces to Move into Tropical Projects

Passivhaus (which is called PH1) is a common all-climatic zones standard "from Alaska to Ghana". There is an impression, however, that the international passive house as the most energy-saving house of modern civilization does not extensively look into tropical buildings with the increasing 50% of the world population by 2030 or 2040 as mentioned in Figure 2 [28].

Over five years ago, "Passivhaus goes South" looked promising to people who understood the PH concept, some following the strict codex and some deviating as presented below in Table 3. After a brief review "PH goes south" below, a sharing of three reasons that might be responsible for why PH did not (yet) capture the heat of the moment are followed:

The first attempts going south publicly involved reaching out to Singapore as perhaps the most vibrant tropical hub for building technology (2016). Apart from very few but workable applications, the idea to include the tropical belt on a larger scale of economy was initiated and introduced to the tropics at Singapore engineered by a dedicated booth during the BEX Green Building exposition 5–7 September 2016. In December, the IPHA-expert Jürgen Schnieders in charge of tropical expansion of the Passivhaus held a speech before 20 professionals organized by the Singaporean Business Council [29]. Despite speech congratulations of most representatives who showed up instead of their senior managers, the resonance remained nil. In the database it was found even two certified passive house consultants on Singapore island, but professionally, they do not have much to do with what they were trained for. They did *patchwork* passive design, but *integrated* approaches following the entire five Passive House principles were not in the pipeline.

Subsequently, the first representation of the "Tropically adapted Passive House" as attempt to create visibility in the tropics was initiated at the International Green Building Conference Singapore, 6–10 September 2016. Four regional undisclosed Insulation, Shading and Coating partners sponsored the making of an exposition booth, issuing a brochure of the IPHA (the International Passive House Association). This first step is witnessed on the homepage "www.profwagnerkarl.com".

Apart from this self-financed and sponsored representation, the conventional PH1 as a universal approach creates viability and reliability for the construction at the same time. In 2017, an estimated number of 65,000 projects worldwide in every climatic region evolved [30]. It can be perceived as a pity to see that the runaway train called climate catastrophe gets more mileage even though Passive House related smart solution are not applied. Looking at the PH1 global map [31], the tropical region with the highest population now and even more in the future seem to be reduced to those addressed 6–7 implementations, as described depending on how we use the definition of "tropical" [32].

Table 3. Passive Homes—Content Analysis with a Synergetic Comparison of PH1 and PH2.

	Passivhaus (PH1)	**PH2 (e.g. Related to ZEMCH)**
Standard	Strict standards in terms of the whole building envelope.	So far no standard, instead of "zero energy", zero carbon as target.
Certification	Detailed certification based on Passivhaus software. Many houses do not apply for the costly procedure.	No certification required, justification as "zero carbon" and "mass customized homes".
Airtightness vs. natural ventilation	Airtightness is a must, no compatibility with natural ventilation. Occupants still may open the windows temporarily if they feel to do so.	Airtightness is a logical consequence, if the outside temperature is too high. Otherwise oprning windows, might depend more on the occupants' preferences and/or the seasonal necessity (e.g., hot vs. rainy vs. cool season)

Table 3. *Cont.*

	Passivhaus (PH1)	PH2 (e.g. Related to ZEMCH)
USL-(Upper Space Limit) Temperature and Humidity in tropical countries applications	USL in PHPP-software tied up to maximum 25 °C. Allowed not more than exceptional 10% excess. (>1 °C lower than tropical ASHRAE standard) The highest relative humidity international benchmark 60% cannot be exceeded in the software (absolute humidity < 20% (12 g/kg)	USL depends on user's preferences (adaptive thermal comfort, i.e., especially ambient temperature) [33] Not much effort is put on the relative humidity, because dehumdifying will cost lots of budget.
Implementations	65,000 (estimation according to Passive House publications) [34]	A few, probably less than 10, but of growing interest of ZEMCH "impact".
Material	Full flexibility, the more sustainable, the better. However, there is a preferred list in the PH-course manual.	Very flexible in terms of material selection.
Community	20,000 experts around the globe (according to Passive House officials replicated by the global map)	Board meeting virtually once a month. Around 800 followers in LinkedIn group.
Economic dimension	Payback periods compared with conventional buildings vary a lot between 5 years for low cost and 30 years for more sophisticated projects [35]	Economy/Affordability comes first for the focus of PH2

4. Four Possible Reasons Why the Passive House Concept (PH1) Has Issues When Entering the Tropical Belt

The following reasons might be responsible, and below how to propose a way out using synergies between all mentioned PH1-approaches and ZEMCH will be investigated:

(1) Numerous inquiries by government-linked companies (GLCs) and various local and international knowledge suppliers for "passive design" witness the call to identify the urgency to build in order to target awareness of the benefits compared with conventional housing with any of the PHs. However, holistic passive houses are not just a mixture of the seven or eight passive design elements. Neither are they patented or trademarked; all rules and tools are published, not pursuing or committed to a certain technology. In the colder hemisphere, basically everyone can build a holistic passive house with material and energy of their own choosing, as long as the builder can yield the astonishingly low energy consumption of 20 KW/sqm and an average heat transmission value of U < 0.15 W/m2K. Mainly, or exclusively, a PH planner/consultant with the PHPP software could handle the projects that after being successful in warm Mediterranean climates are rarely happening "further south". The software created is detailed and accurate, but it creates strict norms which also in future might be hard to achieve especially for the vast majority of affordable homes, when the upper interior temperature limit is 25 °C at a relative humidity of 60%. Hence, it is understandable that the conventional PH is restricted to just 6 or 7 tropical certified implementations, whereas the count for other climates adds up to 65,000 in a growing number [36].) Of course, the actual number of tropical installations can vary, depending on where we draw the line between "tropical" and "subtropical", as elaborated by Köppen (1894) and further detailed out by Geiger (1954), which we adapted from ref. [37].

If, by 2050, 50% of the world's population live in the tropical area without the necessity of heating, then extensive research and development needs to be undertaken to integrate the ideas of the promising Passivhaus approach.

(2) It is mandatory for the Passivhaus approach to expect their certified buildings following exactly the same strict worldwide standard. Even their Passive House Planning Package (PHPP) software, which is required to plan and after construction certification, will treat every passive house on the globe the same way what the output is concerned: energy

efficiency plus thermal comfort, today including indoor air quality. Without airtightness and a heat-recovery ventilation system, the conventional Passivhaus does not work. These are two conditions that with a few exceptions [31] PH in practice will hardly work for tropical houses. Despite the death tolls during pollution and recent heat waves in India [38] open air style is still common—not only for the underprivileged, but also for populations who are educated to dwell less upon “natural ventilation” [39]. This is a common buzzword in countries like Singapore or Brazil, failing to recognize that “ventilation” due to the lack of permanent optimum-positioned velocity is extraordinarily rare, and only smart airtight solutions often including the usage of air conditioners are hard to find.

(3) According to the previous research, the well-insulated, basically almost airtight and optimum shaded building with ventilation performs cooler in almost all cases during the rainy season and the increasing number of transition periods [40]. COVID-19 could be a driver to implement more mechanical cross ventilation not only in tropical passive houses. Without aircon and due to the lack of a moisture barrier it remained humid, especially when drawing night air into the building. However, no harm for occupants and the building envelope could be reported over a 3-year pilot run.

Therefore, passive holistic design will work best i.e., energy efficiently in a combination of (a) nighttime active usage of green cooling (i.e., cross ventilation or water-based cooling ceilings). During (b) daytime, among other related modules looked in, with the air conditioner as a substitute to generate lower temperatures, cooling is mainly based upon passive envelope features PLUS shading.

Compared to the almost 20,000 Passive House planners in Europe and the US, according to another global map of the International Passivhaus Institute, so far just about 16 consultants are certified in the tropical belt. Most of them are working as open-minded architects, but it seems difficult to convince clients to venture into complete PHs. The reason might be that airtightness is often seen as incompatible with natural ventilation, which is still the common trend for low-cost buildings. In addition, in the whole Africa (the world’s second-largest, second-most populous and herein fastest growing continent accounting for already 1.3 billion people (2020) [41] with eminent problems of threatening climate change, not a single expert or project can be found. One might guess that PHs might not be the correct approach for the underprivileged. Whether a ZEMC-Home in whatever combination with the Passivhaus has the potential, which will be briefly discussed in Section 5.

Different than the PH, ZEMCH explicitly is researching and developing solutions both for the poor and the still neglected tropical area. Regions like the tropics might just be applicable for a few selected projects, and Africa simply does not provide a market place for Passive House developers who again use insulation and airtightness as necessary pillars of their concept.

(4) According to the detailed description of the global map, the Passivhaus approach focuses more on individual housing rather than on standard housing. Nonetheless, huge developments like the Bahnstadt [42] or the biggest upcoming Passivhaus settlement in China [43] are still exceptional and no mass product like former socialist residential high rises and plenty of homes built thereafter. Of course, “standardized” means saving costs as much as possible and economically cheap. Nevertheless, this label has not automatically to do with sustainability. ENDLESS unsustainable condominiums around the Globe with mid-class and high-class occupants complete the list, probably with a growing number of a few exceptions.

Apart from the costs for the less privileged, it is hard to convince simple people to follow their rules of insulation, airtightness, and mechanical ventilation to name three of the PHs better known original big five PH-elements elaborated on in Figure 1 [44].

5. Conclusions: Synergies of Passive House 1 and 2 to Make the Concept of Sustainable Homes a Reality

Our last chapter of this tabled comparative content analysis is no longer directly on the tropical adapted Passive House (PH2), which is nowhere practiced. Instead, the questions of if and how PH2 can support the implementation of more airtight well insulated Passive Houses especially in the already or soon to be overpopulated regions of tropical countries will be elaborated on. In return, how can passive house technology assist to make more affordable PH2-homes to become a reality of the hotter future to create real potential airtight and well insulated living boxes for the hot years to come [45]? In the end, PH1 and PH2 are no competitors. Scalable carbon saving is the important target point of future homes, not the intellectual origin of its developer.

In between other approaches to reduce global warming in the built environment (like the mentioned low energy houses and net zero energy buildings), finally it would be liked to point out similarities and possible differences between Passive Houses and PH2 homes. There is no automatic strong link between "passive" and "affordable homes". As a reference model, I would like to refer to the modular Living Box Home created by Antonio Frattari in his ZEMCH project (2013) [46]. Built as mobile application, it utilises the airtight Passive House technology and other adapted features.

Set up first in Bolzano, Italy, the house indicates that the investment costs of a ZEMCH-home equipped with PV (photovoltaics) are almost equal to a conventional one. Hence, if the (usual carbon-triggering heating or cooling demands) are engineered with PV, the house has very low operational costs making questions of payback superfluous. This selling argument counts already for at least a Northern part of a Mediterranean country like Italy, but as shown above, so far it has been hardly demonstrated farther south than Europe.

Summing up, in Table 3 are the main differences as they seem to be laid out in the explicit Passivhaus approach (that called PH1) and the lenient, but more consumer-oriented PH2 had been devised in this entry.

Even though the focus as laid out in Tables 1–3 is slightly different between PH1 and PH2, plenty of potential synergies can be found. PH2's openness without certification and binding software tools and the will to go for "zero carbon homes" could pose an alternative. It is explicitly meant for "affordable" and specific for "homes", regardless if they are found in Minneapolis, Bangalore, Lagos or Bhutan. It could also occur that a PH2-home can be purposely built to be certified before and after its construction.

Reducing CO_2 in Passivhaus-adapted affordable tropical Homes must be realistic for the supply of sustainable homes for millions of people. Therefore, 4. and 5. might be attractive. So far, in terms of organization and applications the worldwide accredited PH1 is the giant, whereas PH2 appears like the little dwarf doing mainly academic groundwork. However, PH2 moves into the area of impact which is covered by PH1 just by their standards. Additionally, as mentioned in Table 3, PH2 has much higher flexibilities.

The bottom line of the tropically adapted Passivhaus PH2 that needs to be discussed further is the mid-term 2030 real and potential societal impact in the wake of the 2050 tropical heating effects that are to be expected. By then, PH2 and related housings could be a kind of a lifeline for homes that otherwise would have to be abandoned causing millions of people to migrate into still all seasons long habitable regions away from the tropical corridor.

Under the impact of the recent IPCC-reports, the idea of producing sustainable buildings which look for environmental solutions to reduce the residential buildings' carbon footprint [47] PLUS decent indoor air quality is getting more common. Green certification tools have adopted sustainability for the planet and people's health. However, as their standards were predominantly developed by architects and civil engineers, apart from (a) carbon footprint reduction and (b) better and cooler indoor air quality, they have not focused on (c) economic needs as the third dimension of a triple sustainable home. Once embarking on green, it would increase the viability of the tool as it shows the user how to bring down their current cost structures. The target defined by ZEMCH adapting to matching PH-elements as far as possible will be to find and convince developers and then buyers primarily on the mass market [48]. In so doing, the tabled commonalities and differences elaborated on and presented above can help as a guideline.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: This entry did not report any own quantifiable data, because it used the devised ideal-typological method that is derived from the Schools of phenomenology, hermeneutics and pragmatism.

Conflicts of Interest: The author declares no conflict of interest.

Nomenclature/Glossary

A/C	Air Condition
GLC	Government-linked Company
IPCC	Intergovernmental Panel on Climate Change
IPHA	International Passive House Association
NZEB	nearly zero-emission building
PH	Passivhaus
PHPP	Passivhaus Planning Project (Software)
PV	Photovoltaics
USL	Upper Space Limit (statistical upper borderline)
VRF	Variable Refrigerant Flow
ZEMCH	Zero Energy Mass Custom Homes

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