Figure 1. Example of existing Nepalese greenhouses

Greenhouse Design Project

The central idea is the development of a sustainable greenhouse vegetable production system in Nepal to be applied at relatively low cost. This not only implies a more closed greenhouse system but also implies the strategies how to grow the crop efficiently in this greenhouse. This will be quite different from the open greenhouses with open side walls and closed roofs as shown in figure 1 applied nowadays. With a more closed greenhouse operating well at Nepalese social and climate conditions further steps can be made to a system needing a low level of plant protection chemicals and producing high quality cropswith also high production level.

From an analysis of limited Nepalese weather data during our 2018 meeting we already observed that out door climate conditions show low wind speed during most of the time and that high wind speed may occur during some short periods. This was supported by your own observations. Having high solar radiation levels at the Nepalese Northern Latitude of about 28degrees we also discussed that cooling by ventilation is crucial in such a greenhouse. The natural cooling of a greenhouse at low wind speed must be driven by the indoor-outdoor temperature difference, so the greenhouse must be designed as a chimney with openings both in the side wall and in the top. Then the hot greenhouse air escapes though the top openings in the top of the roof and cold outdoor air enters through the openings in the side walls. This is also called vertical ventilation to distinguish it from horizontal ventilation by wind forces. To have sufficient side wall openings compared to the top openings this greenhouse must be single span. So it was expected that multispan greenhouses show overheating.

The Nepalese climate conditions also show in generally a fairly high relative humidity (RH) so evaporative cooling with e.g. pad and fan cooling (designed for desert climates with low RH) is not applicable.

During the 2018 meeting we already discussed an intuitive sketch of such a “chimney” greenhouse. If the construction could be realized with the local available material bamboo then costs will be low and it can be constructed locally. Howeverfor a proper design we need to know the best geometry with efficient application of bamboo, we need to know if this design will withstand the strong wind forces appearing during short periods and we need to know if the indoor climate realized in this greenhouse at Nepalese climate conditions will be suited to produce a high quality crop at high production level. Therefore our effort coming back in The Netherlands was aimed at a reliable greenhouse design for Nepalese climate and social conditions (first challenge) and at investigating if the realized climate in this designed greenhouse will be suited for efficient production of a high quality crop at Nepalese climate conditions (second challenge).

Greenhouse design

To meet the first challenge we contacted Dr. Wim de Groot, staff member at both Eindhoven Technical University (TUE), department of the Built Environment and at Timber Research Institute (SRI), expert in Timber Structures and having great expertise on bamboo constructions. He enthusiastically responded to our bamboo greenhouse design problem. Under his supervision Leonie van der Molen and Hidde Lansink, two students Structural Engineering and Design at TUE performed a Masters project on the design of the Nepalese bamboo greenhouse with vertical ventilation. With an open mind Leonie and Hidde have designed various options. After this creative process they could apply a decision matrix to choose the most promising two designs. For these final designs possible junctions were proposed and extensive force analyses were performed for high wind load, not only on the bamboo rod construction but also on the junctions. Also some tests could be performed at SRI on the junctions. The designs were adapted to cope with the sometimes appearing high wind forces.

Design 1 is shown in figure 2. The basic dimensions show the height of both the roof opening and side wall openings of about 1 m.It was estimated that this height allows the mounting of insect nets in these openings to keep the bad insects out (decrease pressure of plagues) and keep the good insects in (allows application of Integrated Pest Management (IPM)).Each span needs four supporting ground units (to be made from concrete or stone) to separate the bamboo rods from the wet soil preventing bamboo rotting there.

The greenhouse width of 8m allows 6 crop rows. The 3 paths wide enough for crop nursing are between the 1st and 2nd, between the 3th and 4th and between 5th and 6thcrop row. The triangle rods to ensure perpendicular rigidity of the construction allow sufficient free height in the first and last working path.

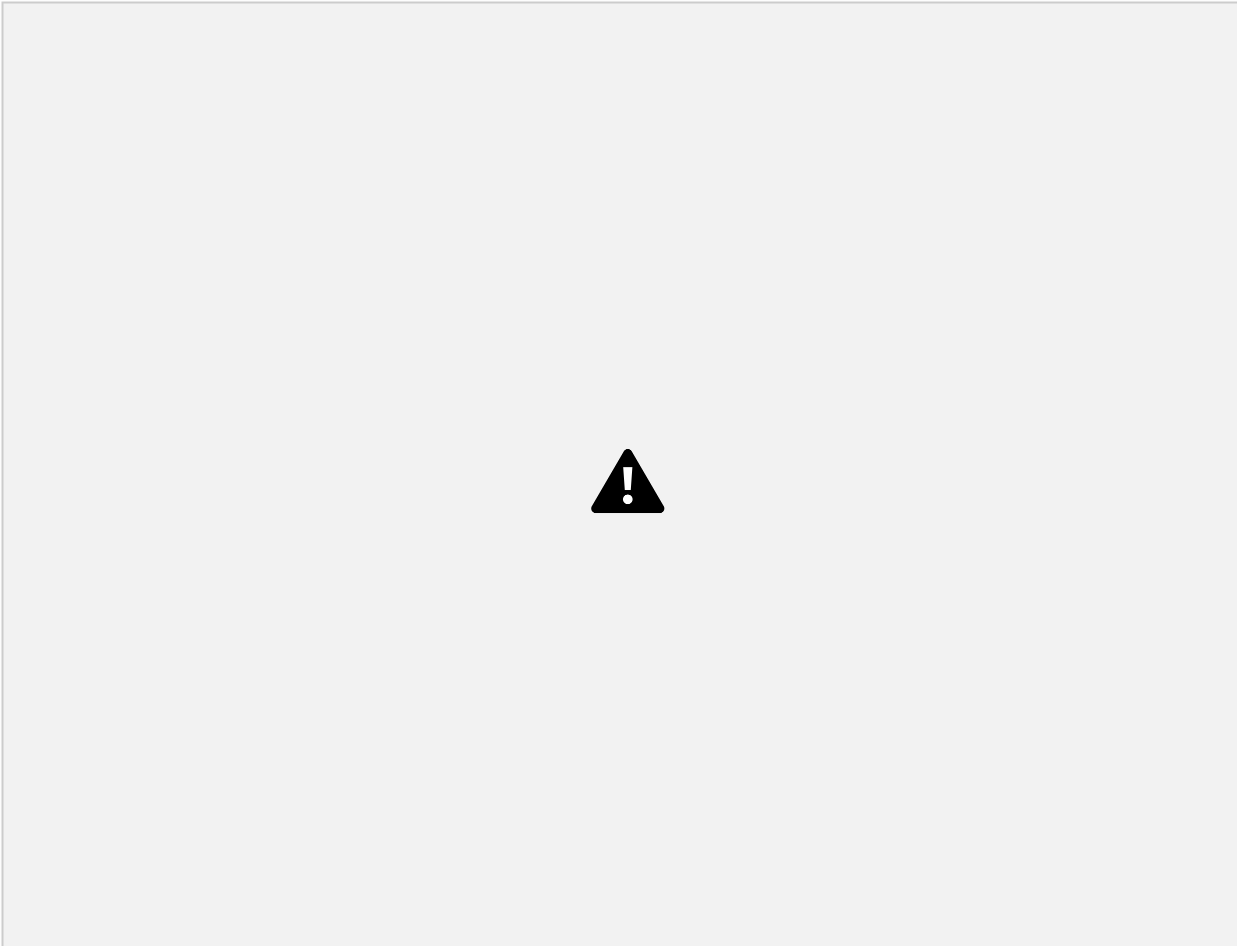

Figure 3 shows a 3-D artist impression of the construction

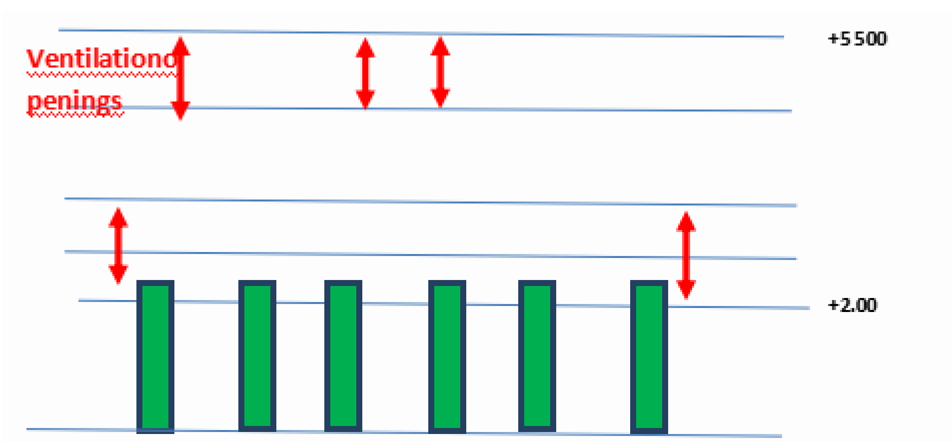

Figure 2. Design 1

Figure 3 shows a 3-D artist impression of the construction. As shown here an entrance compartment allows changing of cloths, disinfection of tools etc. to prevent the transport of plagues and diseases into the greenhouse.

The curving of the applied bamboo rods may be difficult, so the design can be easily adopted to a non-curved roof with roof angle of 30o as shown in figure 4.

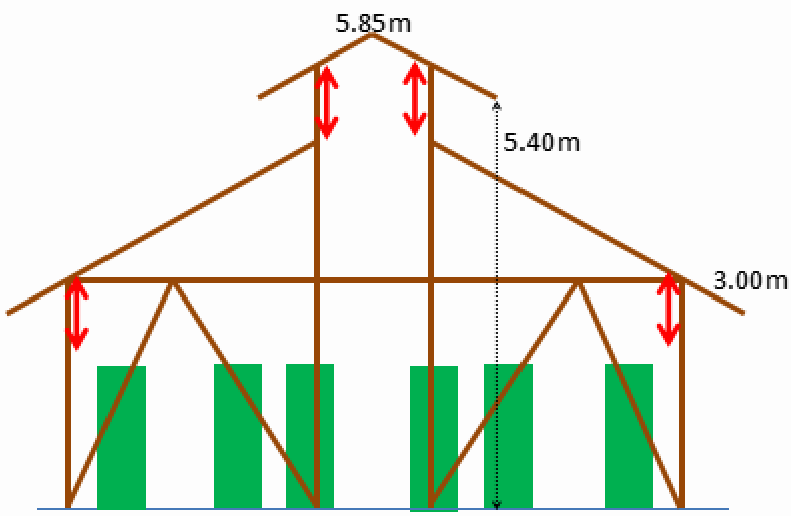

Figure 4. Design 1badapted with non-curved roof

Design 2 is shown in figure 5. The perpendicular stability is ensured by the triangles in the roofs and side walls with the advantage of having only two supporting ground units per span. The design is a-symmetric, the top-opening being 1.2m, the orientation will be perpendicular to the wind direction during strong winds.

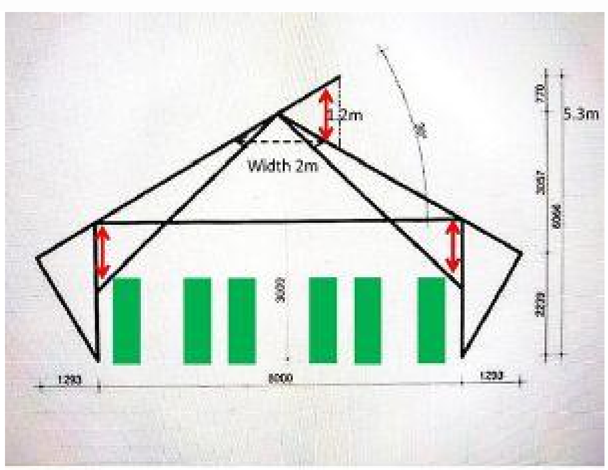

Figure 5. Design 2

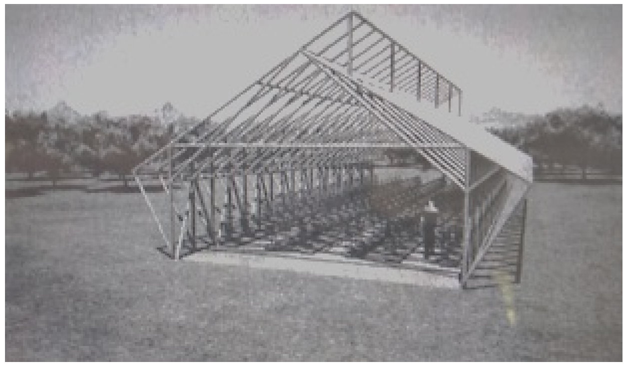

Figure 6. Three dimensional artist impression of design 2

Also some types of connections between the bamboo rods were tested. After analysis the designs proved to be stable at heavy wind load so were ready to be judged if the realized indoor climate at Nepalese climate conditions will be suited for efficient crop production (challenge 2).

Realized Greenhouse Climate

To meet challenge 2 we contacted Dr. Esteban Baeza Romero of the Greenhouse Technology Group of Wageningen University and Research (WUR), expert in greenhouse climate models. These models enable the calculation of greenhouse climate conditionsfor any greenhouse type at any set of outdoor climate conditions. These models have been extensively validated, calibrated and checked for worldwide appearing climate conditions and greenhouse types and have proven to give realistic results. We were able to formulate a so called Seed Money Project (SMP) which was granted so Dr. Romero could indeed perform the model simulations.

His first step was to find a detailed data set for the Nepalese outdoor climate conditions. Two climates data sets corresponding to Kathmandu airport have been obtained from Solcast, corresponding to years 2018 and 2019. They give hourly values during this year so the simulations were performed for each hour during these years.

The wind data confirmed the low wind speed at Kathmandu. In figure 7 the maximal hourly wind speed per day is presented during a year. These low maximal hourly wind speed indicates that the greenhouse has to be ventilated by the chimney effect (vertical ventilation). In Bleiswijk, The Netherlands, the levels are much higher and here ventilation is mostly driven by the wind effect (horizontal ventilation). It must be noted that instantaneous gusts can be higher than hourly maximals, so the greenhouse must withstand the wind load of these gusts which was included in the design.

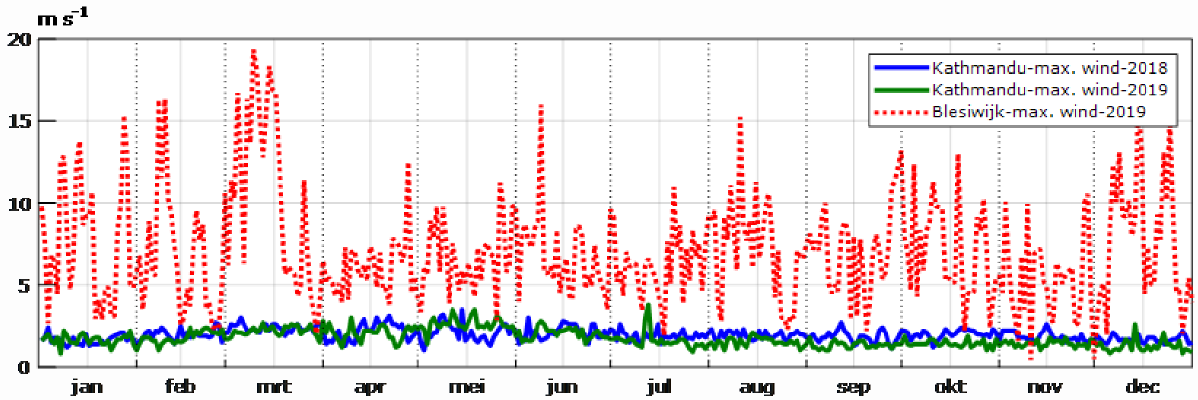

Figure 7 Daily maximal hourly outside wind velocity (m s-1) in Kathmandu (Nepal) in 2018 and 2019 and in Bleiswijk (The Netherlands) in 2019

It was assumed that the greenhouse is covered with standard PE film and that the ventilation openings are covered with low porosity insect nets. In this newsletter we will give the main simulation results for 2019 which were similar to that of 2018.

While the greenhouse is naturally ventilated, a growing cycle starting on first of March (01-03-2019) and ending end of November (30-11-2019) has been simulated, to avoid the cold winter months with temperatures very limiting for crop growth and development. With improvement of climate control from passive to active also production during the winter months can be evaluated but this is for a later stage of development. In the simulations the interaction with the growing and transpiring crop is included. To include the performance of multispan greenhouses also a greenhouse without sidewall openings was simulated.

First it is verified that the proposed greenhouse designs are capable of realizing an optimum temperature range for the crop. The main conclusion is that this is done during most of the time for both designs.

The spring period can be contracted to one day showing the mean hourly temperatures for this average day. Figure 8 indicates that all simulations for the designs that combine both roof

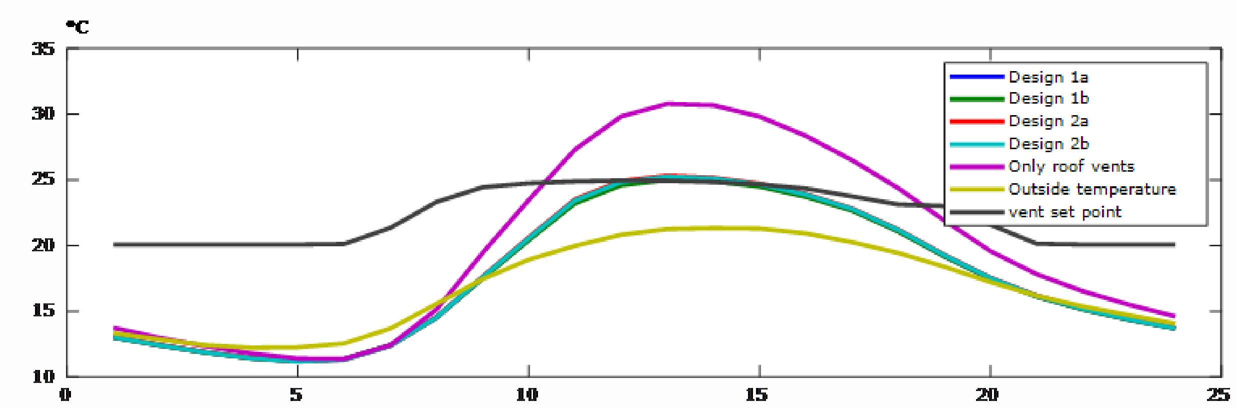

Figure 8 Daily cyclic mean of greenhouse air temperature in the four simulated designs, outside temperature and ventilation set points during the spring period

nd side ventilation manage to maintain greenhouse temperatures within an optimum range during the daytime hours. In the simulations two versions of design 1 (1a and 1b) and design 2 (2a and 2b) are distinguished but they do not differ significantly. The roof top ventilated greenhouse shows high mean levels.

The simulations show that at the start of the growing season in spring minimal greenhouse temperature at day is OK but can be low in the night as indicated by the mean level in figure 8. Therefore a simple manually operated opening-closing mechanism for the ventilation openings is advised.Maximal greenhouse temperaturesprove to be at about 25 $_o$C which is OK. The greenhouse only having roof top ventilation openings (multispan) will easily reach maxima of 30 to 35 $_o$C so is already overheated in spring during the day.

During the whole summer period the simulations show that maximum daily temperatures hardly ever exceed the 28°C threshold for tomato, above which production and quality start to be affected. As a matter of fact, temperature proves to be only slightly higher than outside temperature. On the contrary, if only a roof vent is used, temperatures become excessive most days, so multispan greenhouses are overheated.Minimum temperatures show no problem.

During autumn the simulations show a situation comparable to spring.

The next greenhouse condition is relative humidity, important while too high humidity brings the risk of condensation on leaves and fruits and therefore development of fungi and bad product quality. Therefore also the crop wetness index was calculated to estimate the risk of condensation. During short periods in the nights of spring (small crop) and during longer period in the nights of the autumn (full grown crop) this risk proved to be high. It seems obvious that humidity conditions in this type of passive greenhouse are by far the most limiting factor and special attention must be paid to prevent as much as possible a disease problem. A simple strategy to prevent this could be to use a temporary fixed internal aluminized screen that could be removed manually every morning and mounted every evening during the sensitive periods.

The last aspect simulated is crop production for a tomato crop from the realized greenhouse conditions during the observed cultivation period between March 1 and November 30. The most optimal production per year for this period is predicted to be at a level of about 35 kg/m^2. It needs a well skilled experienced grower to realize this level. Therefore it is crucial that the improvement of the greenhouse system goes hand in hand with development of the growing strategies in this greenhouse and transfer of know-how to the growers. In this way a step by step development will be possible of the greenhouse production system.

Conclusions

The greenhouse climate in the designed bamboo greenhouses with passive chimney effect ventilation (vertical ventilation) proves to be well suited for crop production during most periods of the year. Insect nets in the openings allow application of IPM. For some sensitive periods in spring and autumn a simple manually operated opening and closing mechanism for the ventilation openings will improve temperature control. A fixed internal screen closed during the night will improve humidity control aiming at prevention of diseases. The most optimal crop production is predicted at a level of about 35 kg/m^2 for a cultivation period between March 1 and November 30.

The simulations for the greenhouses with top openings only, representing multispan greenhouses, show overheating during many periods so this type of greenhouse is not applicable at Nepalese climate conditions.

It is crucial to realize these greenhouse designs at an expert and demonstration center in Nepal to test and improve them, gain expertise on crop production strategies in these greenhouses and spread know how to the growers.

Kind regards and good health to all of you,

Dr. Martien Beek

Prof. em. Gerard Bot

Dr. Wim de Groot

Dr. EstebanBaeza Romero

Nelson Man Shrestha