Design Considerations Through Study of Thermal Behaviour of Smart Poles

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Abstract. This paper demonstrates implementation of virtual prototyping approach in early stage of design concept evaluation. Examined structure is of contemporary smart pole design with integrated telecommunication equipment. The combination of integrated design (inside poles) and contemporary electronic equipment thermal management leads to the need of careful examination of thermal behaviour of entire structure. Most important issue is connected to the problem how to transfer generated heat to the environment. Presented study is performed through multiphysics analyses – thermal CFD (Computational Fluid Dynamics) – using virtual prototyping techniques to assess several design variants performance parameters. Used virtual prototypes enable to view in detail heat transfer process and to reach a better solution for cooling components placement. Each design parameter is assessed and further recommendations are formed for design improvement. Final design uses fans placed on the top of the pole structure leading to allowable thermal loads over electronic equipment.

Keywords: Smart pole · Telecommunication · Virtual prototyping · CFD · Heat transfer improvement

1 Introduction

1.1 Study Organization

The first chapter serves as an introduction to the problem at hand and the study focus.

The second chapter presents the methodology used for evaluating the thermal behaviour of a smart pole by virtual prototypes.

The third chapter presents the creation of the virtual prototype and the results from the performed calculations.

The fourth chapter presents general conclusions based on the performed study.

1.2 Study Objective

Commercial cellular networks are handling more traffic than ever as society embraces broadband mobility. Along with macro cellular towers to build out coverage across countryside, carriers and infrastructure providers are deploying smaller equipment to bring antennas closer to the end user. In some cases, these deployments can take place using pole facilities, including utility poles, street lights and traffic signals. A lot of

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examples are available in today's infrastructure that some author defines them as "visual pollution" [1]. Thus, in some cases, new poles can be effective in providing wireless coverage for small-cell networks. When integrated into the network deployment strategy from the start, these "smart" poles can be designed as structures that blend into the environment, may carry the required telecommunication equipment internally inside the pole and provide opportunities for new technologies offered in the future. In these circumstances, existing available infrastructure may not be accessible or in the right location or height to properly position the telecommunication equipment. In other cases, the existing pole infrastructure may be impractical to reinforce, requiring new pole structures. Smart poles can be deployed to supplement or replace existing poles and conform to the existing infrastructure. Smart pole designs must take into consideration the telecommunication equipment to be deployed today and any known future technology requirements [2, 3].

Smart poles require integrated design of electronic equipment through usually built-in solutions. Additionally, the trend for densely populated printed circuit boards (PCB) and high processing speeds of power electronics and telecommunication systems has created a real challenge to develop sustainable thermal management solutions. Electronic equipment should operate within a limited temperature range for acceptable reliability. A large number of research studies in thermal management of electronics have been conducted [4–7].

The combination of an integrated design (inside poles) and a contemporary electronic equipment thermal management leads to the need of a careful examination of thermal behaviour of the entire structure. A major point is to transfer the generated heat to the environment. Among all the available cooling methods, the forced convection air cooling is the most common approach. In this direct heat removal approach, a fan is installed to a heat sink forming an assembly [8]. Air is forced through the heat sink by the fan; thus, the heat is directly transferred to the final heat transfer medium - air [9]. Natural convection or buoyancy-driven heat transfer and fluid flow in enclosures are an important subject in engineering applications such as double pane windows, semiconductor production, nuclear reactor cores, electronic equipment cooling, solar energy technologies, etc. [10]. In the literature, numerous research studies have been undertaken on whether to use natural convection and several research works have revealed that it could have a significant effect on both the thermal performance and of energy consumption cost [11].

1.3 Study Focus. Used Technology

Main focus in this study is set on the decision whether to use *natural convection or forced convection* for thermal management of integrated design of telecommunication equipment and pole. The specifics of examined case are also geographic area of application – a country with tropical climate and high average temperatures.

The aim of the current study is to quantify thermal behaviour of installed inside pole electronics in two major cases – natural (case A) and forced convection (case B).

Another important feature to be considered is the position of outlet – top of the pole or through side vents. This design decision is also important for reaching optimal electronics cooling effect.

Virtual Prototyping (VP) allows to evaluate design at its earliest stage and to check different variants. Its application involves engineering analysis tools that offers possibilities for higher level of exploration of physical processes. This allows to review ongoing processes in detail and to direct design changes in right direction. The numerical simulation gives a better understanding of the underlying physics and allows the user to check rapidly the influence of specific parameters. Another advantage is the cost for a "numerical test" that is significantly lower than for a physical test [12]. VP is very useful in design since they allow the influence of modifications and different parameters to be assessed, directly, without spending time on prototype manufacturing [13].

Examined engineering problem – cooling of installed inside pole electronic equipment – requires to solve a thermal fluid task, or a multiphysics simulation. Fluid flow simulations are known as Computational Fluid Dynamics (CFD) analysis and it has been employed usually to solve the air-side flow and heat transfer. Several tools for multiphysics simulation are already widely used in practice and this facilitates further application of this technique [14–16].

2 Methodology for Pole Mounted Telecommunication Equipment Thermal Behaviour Evaluation Using Virtual Prototyping

The methodology is based on two sets of engineering analyses, based on planned two variants of convection transfer – natural and without active heat sources (type A) and forced (type B). Another option is explored – the placement of exhaust opening of the pole. Variant 1 is oriented to top side of the pole placement of exhaust opening, while variant 2 explores side opening.

Main target is to increase heat transfer to environment. The methodology is shown in general on Fig. 1.

Methodology consists of the following stages:

- **S1: Simulation Model of Physical Process:** This stage examines the possibilities for various designs and ends with generated geometry models;
- **S2: Virtual prototypes simulation:** Separate simulation model are built for each generated geometry of design model. Combinations of convection transfer type (A or B) and opening placement (1 – top and 2 – side) are examined forming 4 simulation models in total.
- **S3: Comparison:** Examined variants are compared by their maximal temperatures for components. Additional review of fluid flow is performed for each variant as to analyse reasons for thermal results. This stage final result is the decision whether an optimal variant could be selected or there is a need for further design improvement.
- **S4: Additional variant(s) virtual prototyping:** This stage is optional and depends on performed comparison and analysis results in stage 3.
- **S5: Final recommendations for design:** Concluding stage of the design improvement process where final design solution is chosen and certain technical recommendations are formed.

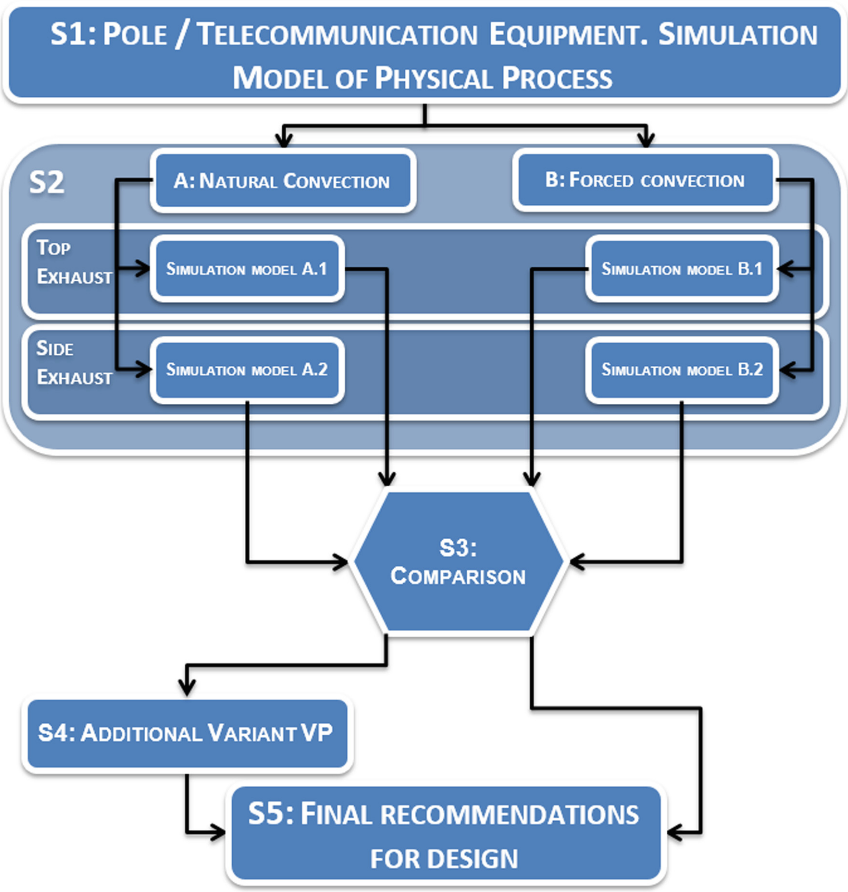

Fig. 1. Methodology for variants assessment.

3 Pole Mounted Telecommunication Equipment Thermal Behaviour Evaluation

3.1 Stage 1: Simulation Model of Physical Process

A simplified geometry model is prepared, based on the initial CAD model of preliminary design and telecommunication equipment placement. Simplification consists of removing small geometric objects that could increase solution complexity without adding any significant accuracy to the results.

Prepared geometry contains also the fluid volume as well as any unnecessary solid bodies are removed – subtracted from fluid volume – as their power losses will be set up through their boundary walls.

Generally, the included solid bodies are: bamboo, steel pole (with detailed ventilation grid) and battery insulation. This model will be used as a basis for all examined cases as the fans are included too. Resultant geometry model is shown on Fig. 2 bellow. Important feature is that due to its symmetry, the design is presented by a half model. The materials used in the design have properties as are listed in Table 1 below, according to parts designation on Fig. 2.

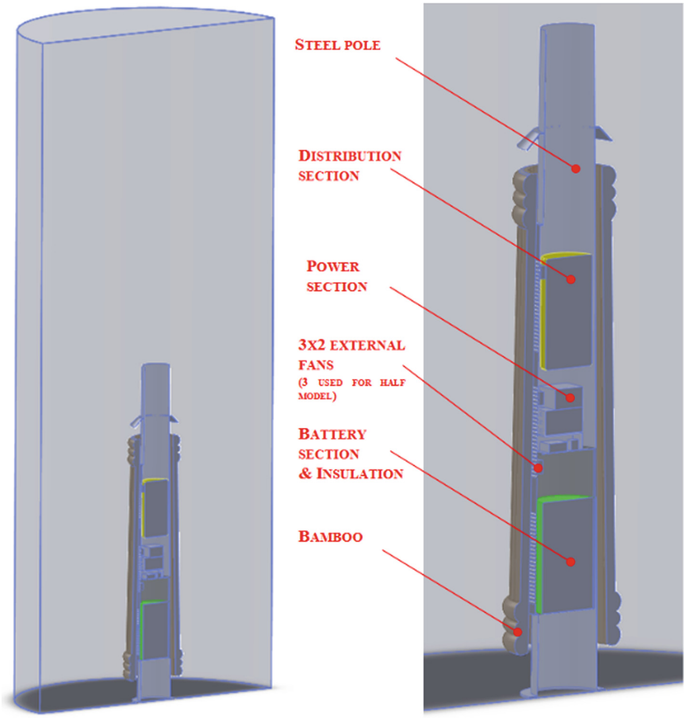

Fig. 2. Simplified geometry model and modelled fluid zone

Thermal CFD analysis explores the contained in assembly fluid as well as solid bodies. Thus, numerical simulation model contains fluid zones – surrounding zone and internal zones, as well as the included three solid bodies (steel pole, battery insulation and bamboo). The model contains approximately 2 220 000 cells and 660 000 nodes.

All applied fluid flow boundary conditions and general view of meshed structural components are shown on Fig. 3.

All fans of power section use common parameters, and especially having work point of:

$$p = 0.32\,\text{in}{-}H_2O\,(80\,\text{Pa}) \quad (1)$$

$$q = 2.21\,m^3/\text{min}. \quad (2)$$

Table 1. Materials, used in simulation models

Mat #	Name	Density, ρ, kg/m^3	Thermal conductivity, λ, W/m*K	Emissivity, ε
1	Steel S355 (used for pole)	7850	50	0.5
2	Bamboo	900	0.18	0.9
3	Battery insulation	2000	0.0328 @ 23 °C; 0.0383 @ 46 °C; 0.0416 @ 50 °C	0.8

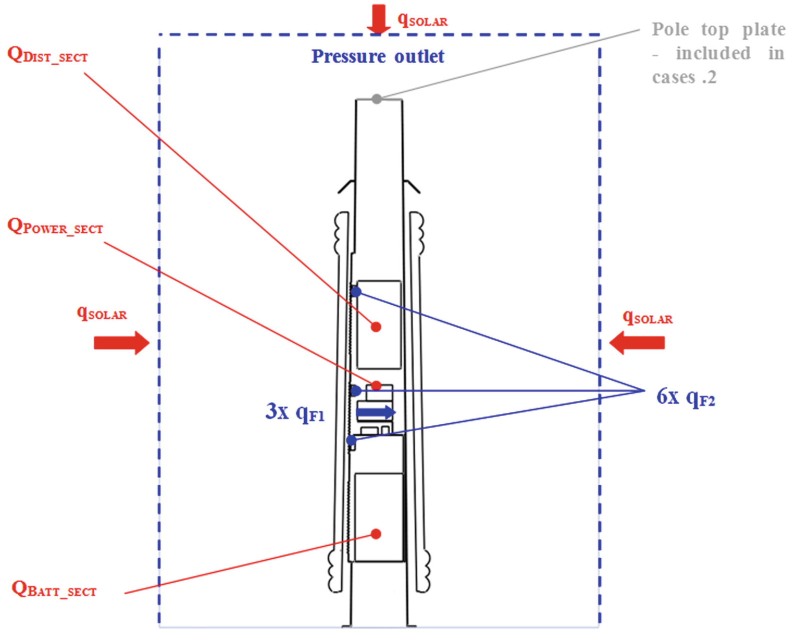

Fig. 3. Multiphysics (thermo-CFD) analyses – applied boundary conditions. Meshed model

Sun direction vector, used in simulations, corresponds to global position of: longitude: 25° and latitude: 20°, and for date 01-July, time: 13:00 h relative to the pole axis.

Power losses in the major components are included according to the received technical specification:

- Battery Section: 120 W;
- Power Section: 350 W;
- Distribution Section: 625 W.

Included boundary conditions for each examined case are summarized in Table 2 below.

Table 2. Summary of applied BCs

Parameter	Case A		Case B	
	A.1	A.2	B.1	B.2
Ambient temperature, °C	55			
Exhaust surface	Top of pole	Between bamboo and pole	Top of pole	Between bamboo and pole
Heat transfer BCs				
Solar irradiation, q_{SOLAR}, W/m^2	325			
Power loss in distribution section, Q_{DIST_SECT}, W	0	0	625	625
Power loss in power section, Q_{POWER_SECT}, W	0	0	350	350
Power loss in battery section, Q_{BATT_SECT}, W	0	0	120	120
Fluid flow BCs				
Fluid flow of power section fan, q_{F1}, m^3/min	0	0	0.27	0.27
Fluid flow of external fan, q_{F2}, m^3/min	0	0	2.83	2.83

3.2 Stage 2: Virtual Prototypes Simulation

The results from the examined four separate analyses are presented by fluid flow and by temperatures. These presentations aim to have direct visual comparison among examined cases and to qualify potential of each variant. Fluid flow parameter of velocity is used as representative for intensity of heated air transport and temperature distributions are used for observation of critically loaded components for further design improvement.

The velocity fields are shown as contours on Fig. 4 for both “no load, natural” case A and for “forced convection” case B – with exhaust through pole top (cases with indices 1) and between bamboo and pole (cases with indices 2).

Temperature distributions are shown on Fig. 5 – over symmetry plane – again using common scale between 55 °C and 100 °C and by examined cases – “no load, natural” case A and for “forced convection” case B.

3.3 Stage 3: Comparison

Obtained results are analysed and next comments are formed as listed below:

- Major parameter, object of this study, is the temperature for each of the examined components. All results by components are merged and shown in percentages, where subcase A.1 (no internal heat sources, no fans active, open pole top) is used as basis (values for components are shown as 100%). This is shown on Fig. 6 below.

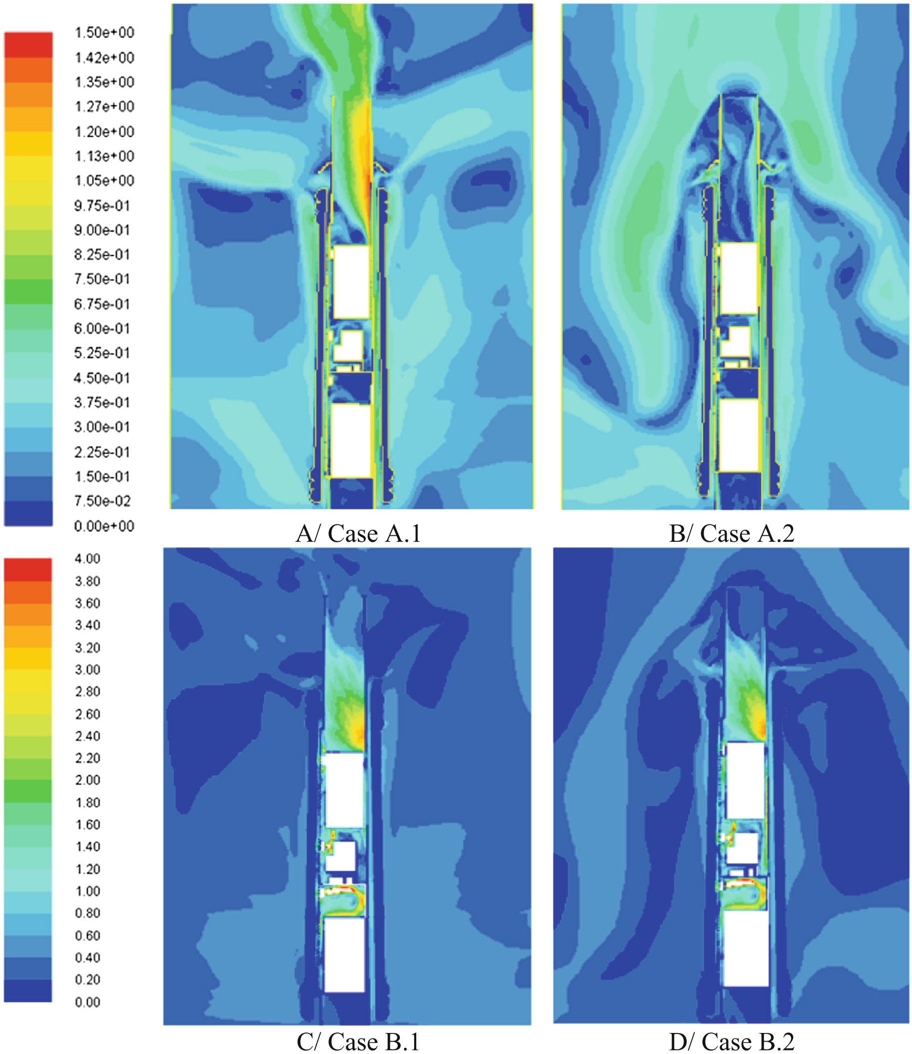

Fig. 4. Contours of velocity magnitude in symmetry plane – for all variants, m/s

- Studying the effect of closing top of the pole, it is seen that distribution section shows major rise of temperature – by 20–30%. Battery section shows also rise of temperature, especially in the case when internal heat flux is added – more than 30%;
- Power section shows no significant rise in any case;
- Studying the effect of switched on fans and internal heat sources, it is seen that most affected components are distribution (up most) and battery section;
- Fans near distribution section (upper pair) are too close to it and are practically ineffective;

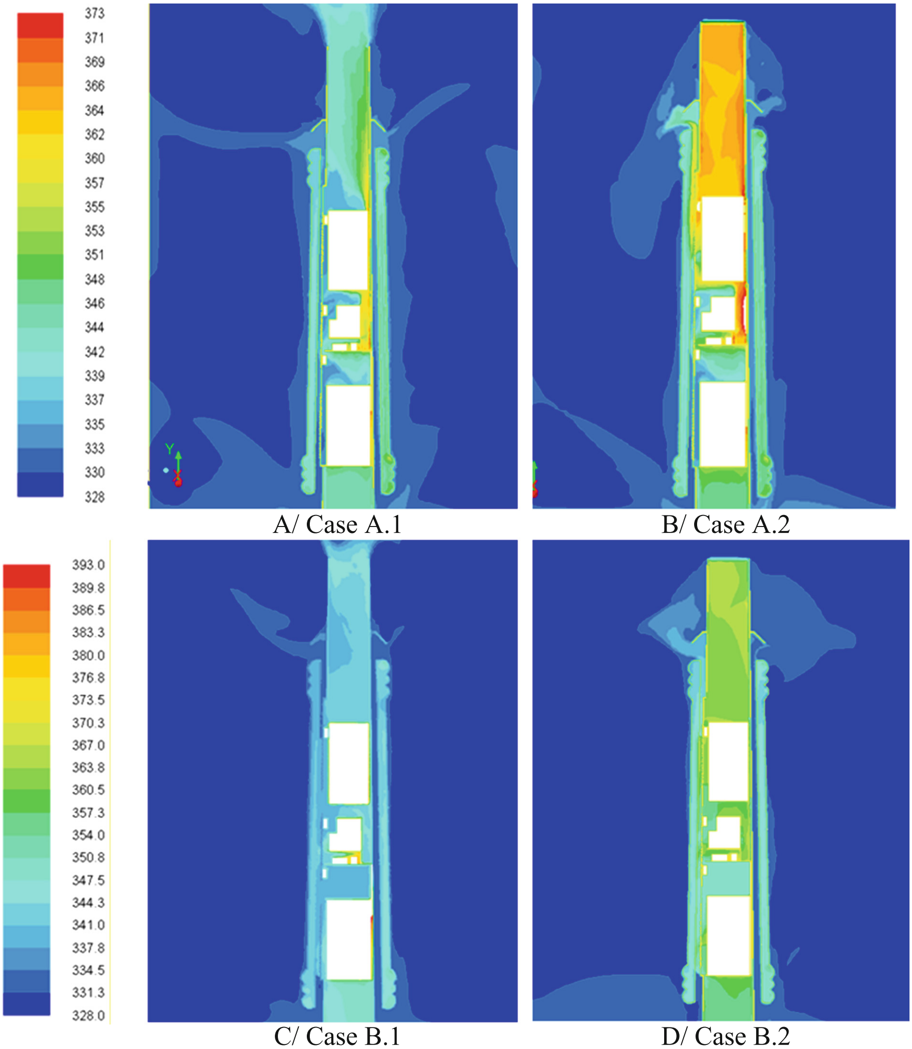

Fig. 5. Contours of temperature distribution fields on symmetry plane, K

- Fans near power section (middle pair) have some effect as it is seen also by temperature comparison on Fig. 6;
- Fans near battery section (bottom side pair) have negative effect as they redirect the flow downwards as form a closed loop inside;
- Exhaust through top of the steel tower is recommended;
- Fans position near the grid is ineffective (all electronic sections are modelled as not porous bodies);
- Improvement could be reached by positioning a group of fans at the top plate of the pole. This will reinforce stack effect and will decrease inside temperature.

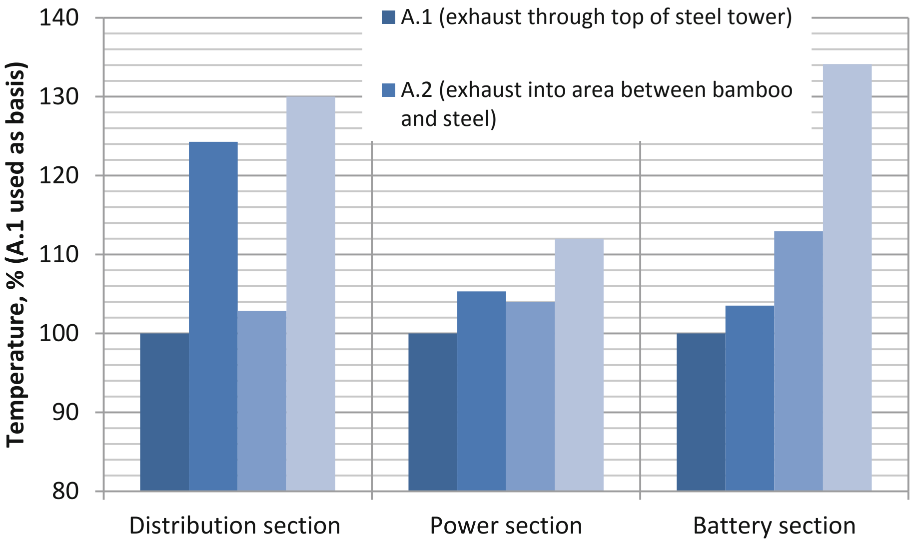

Fig. 6. Comparison among variants by components

3.4 Stage 4: Additional Variant Virtual Prototyping: Fans on Pole Top Plate

Additional simulation is provided to check recommended modification to move fans on pole top plate. Simulation model assumes, for instance, certain fluid flow through the pole top plate, that corresponds to 12 mounted fans HE910028, Fan axial 48 V DC (120X120X38mm)-R Type.

Obtained results for cases C.1 and C.2 are compared together on the updated Fig. 6 graph – shown on Fig. 7.

Several notes are listed below:

- Both distribution and power sections temperatures are decreased and reach values less than obtained with no fans active cases (A.1 and A.2);
- Battery section is still with relatively high temperature, reaching 78 °C.

3.5 Stage 5: Final Recommendations for Design

Examined additional variant shows definitive improvement of overall thermal behaviour of the structure. Components does not reach 80 °C and this design could be further developed in detail. Later improvement could be searched in direction to optimize battery section dissipated power.

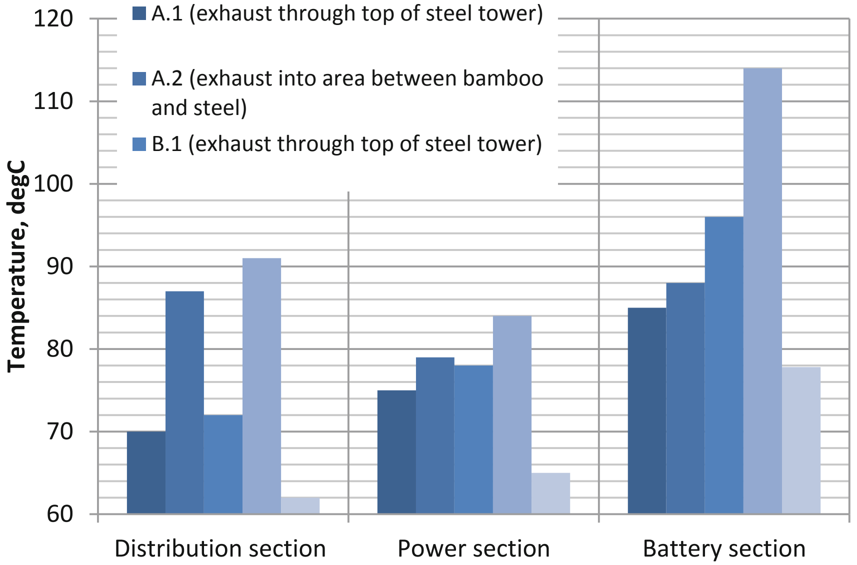

Fig. 7. Comparison among variants by components

4 Conclusions

An innovative design of a pole with integrated telecommunication equipment is developed, based on virtual prototyping. Main outcomes from performed study are:

- Design evaluation at conceptual stage and major decisions based on engineering analyses results. Earlier prediction of functionality and behaviour has major effect to reduce product development cost and time to market;
- Reduction of number of physical prototypes – additionally increases effectiveness of virtual prototyping;
- Direct quantification of physical properties of design and detailed view of physical processes. This is specific advantage of virtual prototyping against physical.

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