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Determination of the optimal configuration of energy recovery ventilator through virtual prototyping and DoE techniques

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Abstract

This study presents an approach based on Design of Experiment (DoE) technique for the optimization of an energy recovery ventilator (ERV). This system is one of the efficient ways to enhance the thermo-hygrometric comfort without increase excessively the thermal load in domestic kitchen. However, there is a major concern, which energy recovery cannot trade off ERV's fan power consumption. The goal of this study is to obtain the information about the relation between factors and response in an empirical way. This approach integrates three different levels of analysis: the virtual prototyping, Design of Experiment (DoE) and rapid prototyping. The virtual analysis allows to define the principal parameterization of a simplified model and to simulate the performance of each configuration at working condition. The proposed approach investigates the effect of the defined parameters and noise factor on the experimental results. In particular, the applied method for DoE analysis is based on virtual experiments in according to the necessity to reduce time and costs during the early design phase. The optimum parameters configuration, which is defined by the previous step, is useful to define the geometry and the working condition of a reliable virtual model. The final level is the realization of a 3D ERV with a rapid prototyping printer. The obtained component is now evaluable at the test bench to investigate the air flow rate and the electric power consumption.

Keywords: Virtual Prototyping; Design of Experiments; Rapid Prototyping; Energy Recovery Ventilator.

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1. Introduction

The goals of the European Community aim to develop a competitive sustainable and safety energy economy. In this sense, domestic appliance producers are faced with the study and research of more efficient products with less environmental impact [1], but that are able to get high performance and functionality [2]. These problems require a flexible design methodology that is able to support the engineer in virtual physical analyses and also in the rapid decision-making processes, in order to increase the quality and the performance of the product. Moreover, the complex dynamics of global markets, force companies to adopt new ways so as to increase their competitiveness. For this purpose have been developed a multidisciplinary approach, where the designer is obliged to consider simultaneously multiple perspectives to determine the optimal solution. Above all, engineer is called to achieve the right compromise among the product features, manufacturing time, cost and performance. This process of optimization is often manual [3] and does not allow a comprehensive exploration of the problem, obtaining solutions that are not always the optimal ones.

Therefore, automated optimization based on the integration of CAD and CAE tools are essential to increase products quality and to facilitate and accelerate the identification of the best configuration. The majority CAD-CAE tools existing on the market are stand-alone systems and they need a relevant user interaction to achieve a real integrated use [3,4].

In this context, the aims of this paper is to develop a methodology that allows, through the effective integration of different design and simulation tools, the multi-objective product optimization.

The approach presented in this paper consists in making a limited number of simulations based on the Design Of Experiments - DoE method [5–8] and the reconstruction of the Response Surface Methodology - RSM [9]. The simulation results are used to create an approximated model of system responses. The approximated model is called surrogate model or metamodel and can be generated using different techniques [10]. From the surrogate model it is possible to analyze thousands of configurations that identify, through the support of appropriate optimization algorithms, the optimal one. The proposed methodology has been applied to find the best configuration of a mechanical ventilation system. This sort of system is used in domestic environments to facilitate the air exchange. We are thus facing a multi-objective design, in which it is necessary to optimize the thermal comfort of the inhabitants and to minimize the energy consumption.

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2. Methodology

This section presents the methodology (shown in Fig.1) studied to support the *energy recovery ventilator - ERV* design for a domestic kitchen.

The achieved methodology integrates three different levels of analysis: virtual prototyping, design optimization and prototyping.

The proposed approach is based on virtual experiments according to the necessity of reducing time and costs during the first design phase. The optimum parameters configuration, defined by the previous step, is useful to define the geometry of a reliable virtual model. The final level is the realization of a 3D ERV with a rapid prototyping printer. The obtained component is now evaluable at the test bench to investigate the performance.

The virtual prototyping level concerns the phases of model simplification, geometrical parameterization and virtual simulation. The simplification of the virtual model is the first step where early analysis identifies the less important geometrical entities. At this level the engineer interacts with CAD tools to reduce the geometrical complexity of the real model. The resulting geometry is a closed volume which excludes through holes, threads, small fillets and chambers, electrical components, etc. The next step includes the parameterization of the main geometrical dimensions. Therefore, the parameters choice is related to the DoE analysis which requires an orthogonal array to plan the virtual experiments.

The design optimization guides the analysis of virtual simulation by identifying a certain number of parameters which influence the performance. The simulation basically regards CFD analysis which reproduces system behavior without physical manufacturing. Through the construction of the response surface it is possible to analyze the product in all operating conditions.

The DoE level provides the experiment plan definition related to the parameters chosen in virtual modeling. The engineer can use his know-how to set the parameters range and to evaluate the most suitable configuration. According to DoE approach, a reduced number of experiments is required to elaborate the final optimum condition. Each test includes a combination of the set values in order to investigate the influence of each parameter. The objective function includes three levels of specifications: the maximization of the ERV performance and the air flow temperature that entry in the kitchen and the minimization of the airstream velocity.

Analizyng the CFD results, it is possible to evaluate the optimum condition and to simulate the elaborated configuration.

The result of the design optimization approach, including the virtual experiments, provides a better parameters configuration. The elaborated settings could be simulated to evaluate the performance with virtual tools. The next step is the rapid prototyping of the better configuration, using a 3D printer tool. At the test bench, the real world experiments can confirm the final analyzed configuration of the printed model.

In the next sections this methodology will be applied in designing of an *energy recovery ventilator - EVR* for a single room ventilation.

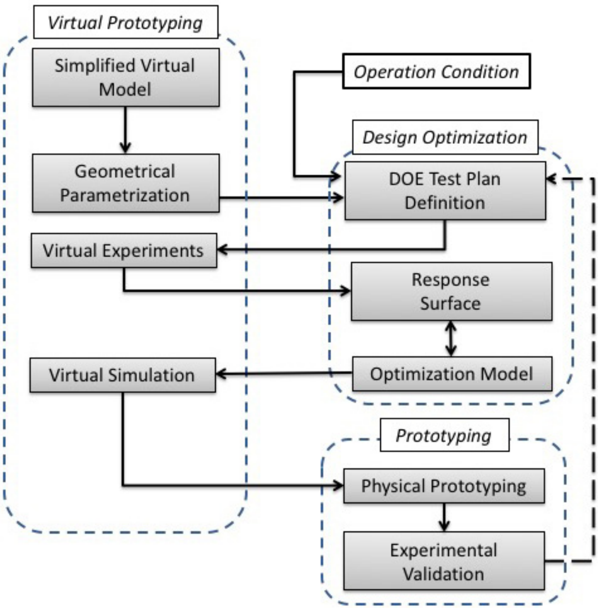

Figure 1: Scheme of the proposed methodology.

3. Numerical model

In this paper, the heat transfer and fluid flow characteristics of ERV are obtained by numerical simulation. The numerical simulation is performed using the commercial CFD code *ANSYS-Fluent*. The numerical model has been verified to be an accurate representation of real world through comparison with experimental test results. The CAD geometry of the model was generated in *SolidEdge*.

3.1. Geometry, mesh and boundary conditions

The geometry of ERV is modeled as a shell-and-tube heat exchanger. In heat transfer application the shell-and-tube heat exchanger is the most common type in use. This system offers several advantages such as: large heat transfer surface area-to-volume, easy manufacturing and disassembly, low cost etc. . .

In Fig.2 is shown the geometry of the ERV, it consists of a bundle of cylindrical tubes enclosed within a cylindrical shell. One fluid flows through the tubes and a second fluid flows within the space between the tubes and the shell.

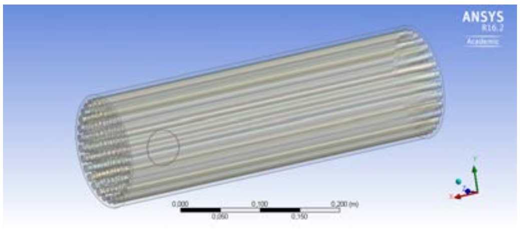

Figure 2: CAD geometry of the Energy Recovery Ventilator.