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Preventing Odor Diffusion: An Innovative Hood Design

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Abstract

This study illustrates the developmental design processes and innovative findings for an efficient cooker hood design that can prevent odor diffusion. Hoods used in kitchens are used to remove smoke generated during cooking. Depending on the type of food, odor usually diffuses away from the kitchen, thereby creating discomfort. Although this problem can be overcome using different designs of cooker hood structures, and by various flow controls, it is known that undesirable conditions persist. In this study, the smoke analysis of a current hood was conducted in an installation known as an island kitchen, and an efficient hood design was developed producing a flow effect to prevent smoke diffusion. In the innovative model, the aim was to prevent smoke diffusion by creating air curtains with reverse air channels added to the current hood. When taking the design decisions, an innovative, performance-based suction system was introduced using time-dependent analyses with the help of a CFD (Computational Fluid Dynamics) program. ANSYS software was used during the development of this innovative hood to analyze the current hood, and the validity of the results was checked by comparing both designs. As a result, CFD analyses showed how the current type of design performs in keeping smoke, temperature and odor in a volume of air flow between the cover and the hood.

1. INTRODUCTION

In the houses of today, it is seen that residential spaces as a necessity of modern life are divided into service, living and sleeping areas. Each section requires various spaces, and each space features areas of activity. The spaces created within the structure of the house for these activities can be private, semi-private and open to the public [1]. The functional and perceptual quality of each residential space, which are created to meet the requirements of the activity, can be achieved by successfully examining the abstract, concrete and functional relationships between the user's needs, the architectural characteristics of the space, the fixed/mobile equipment and any accessories. In short, when relationships between people, space and accessories are kept at an optimum level, positive contributions are made to the user's happiness and comfort [2, 3].

As in other designs, numerous criteria, such as safety, quality, durability, easy maintenance, status, brand, performance, aesthetic-fashion, additional features, environmental compliance, shelf-life, easy installation, packaging and compliance with legal standards are considered for the design of accessories, and their solutions can be provided using different methods [4,5]. It is understood that accessories in residential spaces that are designed according to the requirements of users interact with each other in terms of dimensional standards. For instance, in the process of designing and manufacturing indoor fittings, it is essential to know the standard dimensions and the installation requirements of a built-in (embedded) product when sizing the length and height of a cupboard in a kitchen space to fit an oven.

According to the developed standards, various criteria have been determined by the product characteristics that will carry out the activity in those places. For the best ventilation scenario in the

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design of ventilation and air-conditioning systems in kitchens, it is essential to consider the design criteria listed below [6]:

- The type of kitchen,
- The number of covers prepared in unit time,
- The operating time,
- The indoor geometry,
- The type and attached loads of cookers,
- The installation and dimensions of devices,
- The use of devices at the same time (co-utilization factor).

Increase in design efficiency as a result of considering these criteria can be explained by using different parameters. When the user's opinions are considered along with the relationship between parameters and the designer, it is necessary to consider the experience gained through the process. Analysis software simplifies identification of product deficiencies in the design process. Furthermore, the validity of the proposed solutions can easily be tested. To achieve a realistic product design, it is necessary to select the design characteristics, the technical infrastructure and the appropriate design parameters, and incorporate those relationships into the process using CAD (Computer Aided Design) and the FEM (Finite Element Method). When taking design decisions, the addition of the user's needs into the working environment, the technical characteristics and the features that can affect the form and function of the product, substantially contribute to the product design.

Nowadays, smoke and odor diffusion in kitchens, especially during cooking, directly influences the comfort of the user. For example, women and children are also afflicted with physical discomfort from smoke inhalation and cooking that includes eye irritation, headache, and lower back pain [7,8,9]. Aprovecho Research Center states that "from the perspective of the designer, four goals need to be met to design a stove and hood: cooking effectiveness is the same or better than the traditional method; smoke is eliminated or reduced from the kitchen; less fuel is used; and is producible at an acceptable cost [10]. Although various hood models have various effects on ventilation characteristics due to developing technology, it appears that they continue to be ineffective for some cover combinations [11,12]. In this study, scenario analyses of hoods were carried out according to the number of covers prepared in unit time. In addition, the state of the current model (Model-1), and innovative model (Model-2) conditions were determined by using Computational Fluid Dynamics, depending on the distribution. According to the results of these studies, the idea of creating a reverse direction air curtain in the current hoods was tested on a model kitchen prepared according to standard values in order to prevent smoke and odor diffusion (to meet the user's needs) under normal operation conditions.

CAD and FEM software were used in this study where "user needs-based design" and "developmental design" considerations were combined into the product design. This study illustrates a high capacity, and efficient product design aimed at preventing odor diffusion, and provides a structure with homogeneous temperature distribution. In addition, the relationships between the limitations of the technical parameters and the design decisions in the design process, ranging from simple to complex, were revealed by the computations.

2. DESIGN AND MODELLING

Product design is a targeted problem-solving activity based on human experience, creative thinking and related knowledge [13,14]. Processes differ in many stages from modeling to simulation due to the contribution of information technology. Although it is given a different name in different sources, a process is basically a structure starting with problem detection and ending with an evaluation. However, an increase in simulation skills particularly affects the iterations of a design process, and the evaluation process can lead to a process component that can be repeated many times [13].

In the definition of a traditional design process, a linear model is common. However, a design is characterized by the inclusion of different parameters into the process. To illustrate this, while "environmental design" emphasizes environmental parameters [15], a "user needs-based design" emphasizes individual-user and behavioral elements. A "user needs-based design" is also called a "participatory design" or a "collaborative design"; this is where the user is involved in the design and decision-making processes [16]. In this regard, a design study was conducted to reduce odor diffusion from a hood by combining a collaborative or participatory design with a developmental method.

2.1. Ventilation Standards

A hood is used to keep the ambient air clean by throwing steam and odor out during cooking. Hood types can be classified as island, wall-mounted or ceiling, according to the kitchen plan and their usage. The air flow of the hood is calculated according to the size of the installed hood and the type of operation performed. Determination of the value for a specified flow rate depends on the mounting position of the hood, the characteristics of the operation performed under the hood and the cooking time in the kitchen. Hoods are classified as shown in Table 1.

Table 1. *Hood types and ventilation velocities [6,17]*

Hood Type	Lightweight	Medium	Medium-Heavy	Heavy	Extra Heavy
Wall Type	0.25-0.35 m/s	0.35-0.50 m/s	0.45-0.60 m/s	0.50-0.65 m/s	>0.65 m/s
Island Type	0.40-0.45 m/s	0.45-0.60 m/s	0.55-0.70 m/s	0.60-0.80 m/s	>0.80 m/s
Eyebrow Type	0.25-0.40 m/s	0.25-0.40 m/s	———	———	——
Console Type	0.15-0.30 m/s	0.30-0.50 m/s	0.40-0.60 m/s	0.50-0.65 m/s	Not applicable

2.2. Flow Types in Kitchens

Kitchens are ventilated by using the external air supplied by the hood mechanism [6,12]. Different air flow rates are created by including ventilation systems in the cooking environment. Based on satisfying the climate load criterion, air is distributed in two ways: mixed and laminar flow. Depending on these two flow types, external air characteristics significantly influence the flow field. This intervention, which contributes to the efficiency of the hood, tries to prevent smoke diffusion, and can also cause a distribution effect.

A mixed flow, clean supply air, and the air above the cooking devices produces a mixture that is completely enriched with foreign substances. Dirty kitchen air is diluted with outside air, thus the same temperature values and impurity concentrations are found all around the kitchen. The air supplied at relatively high rates above the human level to meet comfort requirements in living areas intensively mixes indoor air with fresh air.

A mixed flow is divided into two parts according to the distribution points: the horizontal and vertical air supply. In horizontal air supply, the air fed under the room's ceiling creates cylindrical flow areas. These can deflect hot air flows above cooking devices towards work areas and distribute the extraction flows from the hoods of kitchen devices. Ventilation grilles or air nozzles are used as air intakes. In vertical air supply, the mixed flow can be created with a few individual air intakes supplied on the ceiling, or distributed over the ceiling. Mixed and counter-flow fields form around each air intake. The mixing of hot air flows can be reduced by modifying outputs from kitchen devices and the working area. Jet, swirl, radial and linear diffusers are used for such air flow patterns [6].

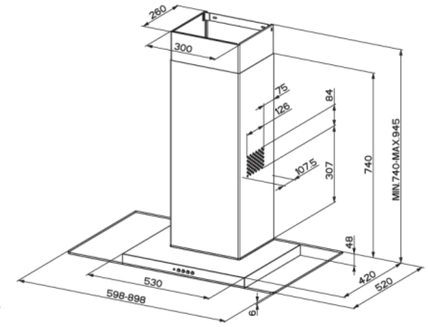
Laminar flows reduce heat and material contamination in areas where people live. In the case of this type of air supply, both the air flow inside the room and the air flows formed above kitchen devices carry hot air that is enriched with impurities, which in turn rise to the hood. If this air flow -formed by heat in the area where people are present- is replaced by an air supply, air pollution can be almost completely prevented, and the pollution due to heat is reduced by 50%. Special care should be given to the air supply velocities so as not to disperse thermal air flows. The efficiency of laminar flows has been shown many times to reduce loads and heat in kitchens. Laminar flow-air distribution elements can be mounted on ceilings or in areas where people are present [6,17].

Under the scope of this study, analyses of the current hood were compared with those of the innovative design model for the same conditions. Using the flow effects that occurred as indicative factors, their compatibility with user requests was investigated. Thus, the validity of the innovative thinking was tested.

2.3. Hood Model

2.3.1. Current Model (Model-1)

The dimensions of the selected island type hood are 700 × 420 mm; and they were positioned to be 70 cm above the bench and the standards prepared in this regard are obeyed. Besides, the dimensional and technical values of the single-suction hood model tested in the study are shown in Figure 1.



Technical Features

- Dimension (width × depth × height): 700 × 420 × 800 mm
- Nominal power: 330 W
- Aspiration flow rate: 400 m^3/h
- 3 different emitting stages
- Sound decibel: 44 dB (A)

Figure 1. *Dimensions and technical features of the Model-1 hood*

Considering the technical parameters of the hood, it has a low noise level, and is effective for the number of covers in unit time given its high aspiration flow rate. The geometric form of this model was prepared using the Autodesk Fusion program and adapted to the kitchen model by transferring it to the ANSYS program for simulation.

2.3.2. Innovative Solution Model (Model-2)

In the innovative model designed to test the main purpose of this study, the idea of an “air curtain” used to establish heat and humidity balance between indoor and outdoor areas was tested on the current hood. Air curtains are systems used as a barrier between indoor and outdoor areas, especially in the workplace and retail supermarkets. Keeping the air exchange between these two environments at a minimum level is important in terms of ambient air quality and energy savings. A minimum level of air exchange between indoor and outdoor areas reduces heat transfer and stabilizes the current humidity balance in an environment [18]. Considering all these characteristics, an innovative idea to prevent smoke, steam and odor was realized by designing air channels into the hood model (Figure 2).

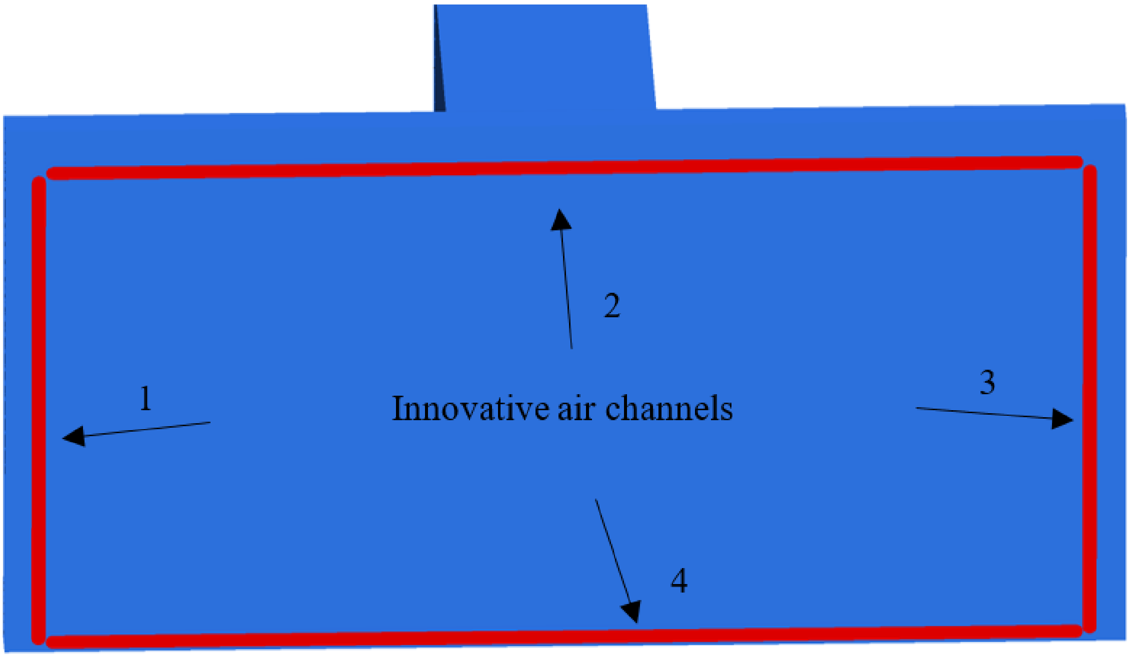


Figure 2. *Hood model and innovative air channels*

The dimensions of the air channels numbered 1 and 3 developed in the innovative frame design are 10 × 350 mm, while the dimensions of the air channels numbered 2 and 4 are 10 × 730 mm.

2.4. Kitchen Model

The island hood—the center of a kitchen— is used in very active kitchens, i.e., places where more than one person works, and where food preparation is carried out. It is also used in places where special visual emphasis is preferred. In this study, an island kitchen model was created in a 3.80 × 6.70 m kitchen with a 2.20 m ceiling height.

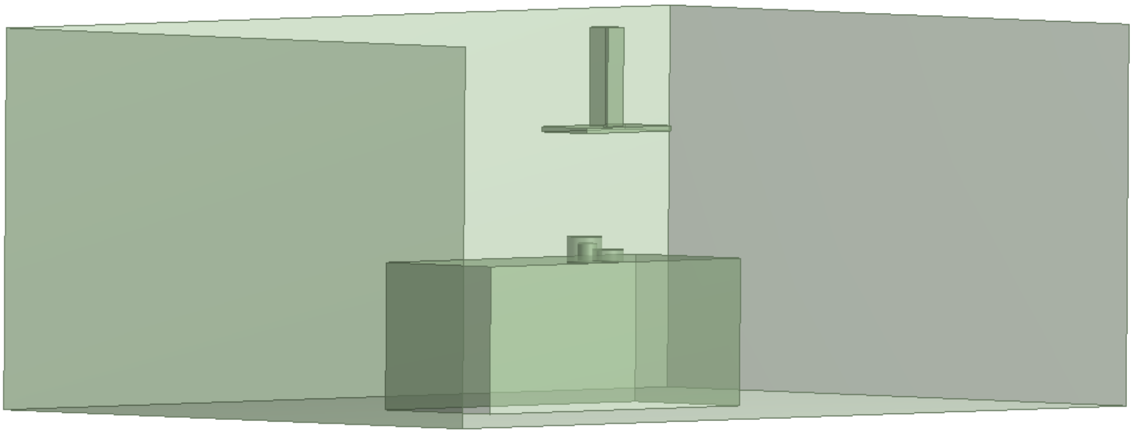


Figure 3. *Island Kitchen and Hood model*

2.5. Boundary Conditions and Solution

In the innovative hood design process, geometry related form studies were performed using the Autodesk Fusion program. Models prepared following this step were transferred to the ANSYS module with the extension ".step". In the ANSYS-Fluent module, flow simulations were defined as time-dependent, multiphase and turbulent flow. Flow simulations were carried out in four stages: the generation of geometric modeling, the performance of node processes, the boundary conditions and analysis module, and the results analysis. In the first stage in each step specified by the developmental design process, the geometries prepared as solid models in the Fusion program were equated to flow volumes using the workbench module, making them suitable for solutions. In the second stage, node generations were performed using the ANSYS-Meshing module for the flow volumes of all models. Approximately 5 million nodes were used in the island kitchen model.

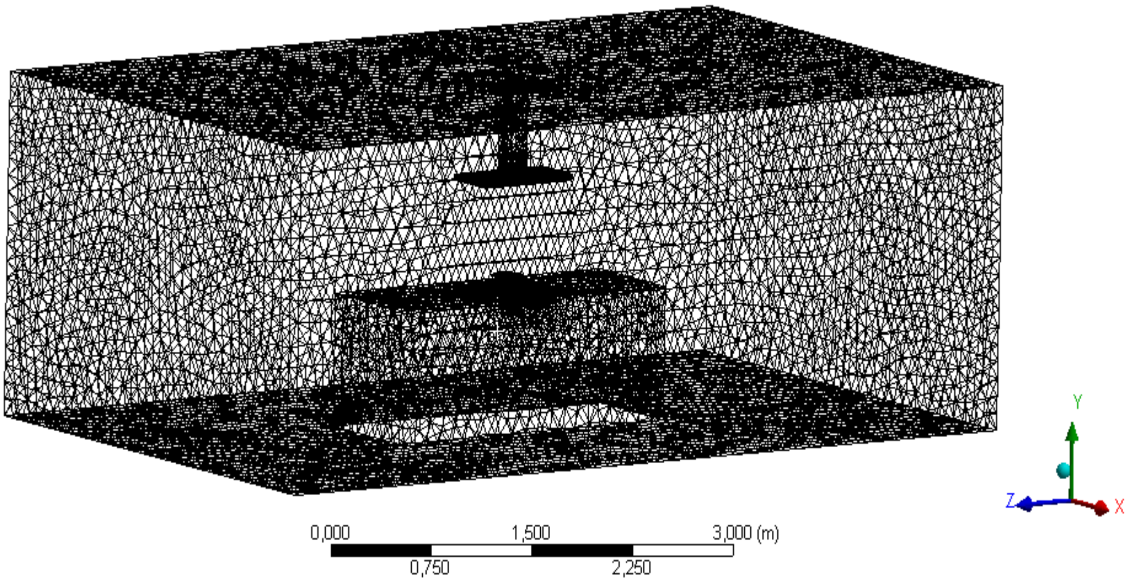


Figure 4. *The node structure of the island kitchen model*

Examining the node qualities, it is known that the quality of skewness improves when it approaches 0 and gets worse when it approaches 1 [19]. The node quality for 95% of the skewness values of the studied nodes was kept below 0.4 (Figure 5) for all solutions.

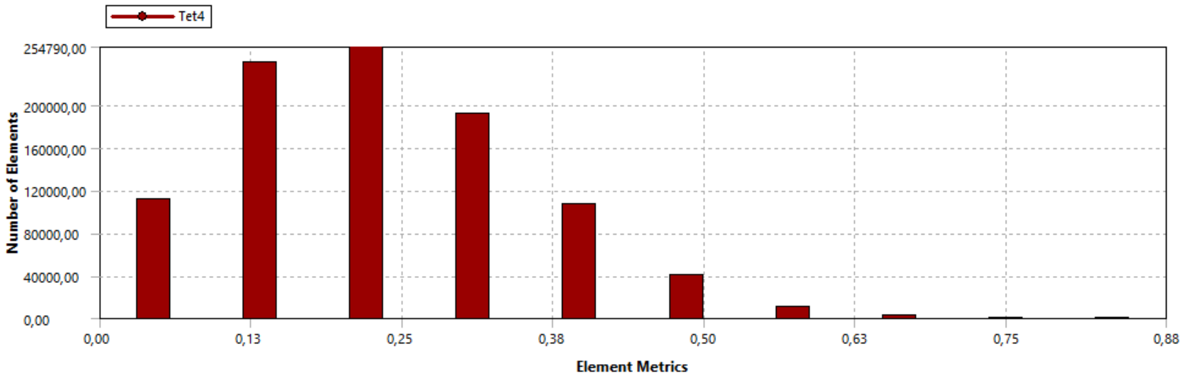


Figure 5. *The node structure result for the island kitchen model*

The third stage used the ANSYS-Fluent program to establish boundary conditions and the analysis processes. In this program, based on the finite element method, the k-ε turbulence model was used. “Velocity inlet” was defined in the boundary conditions released from covers to the environment, while “Pressure Outlet” was defined in the hood chimney, depending on the flow rate. Convergence parameters were reduced to 10^{-5}, and the solutions obtained were selected from the reporting section. In the last stage, the solutions obtained and their numerical values were supported by the visualizations taken from the ANSYS-CFD-Post module. In this study, all models were subjected to this cycle of repetitive analysis until the desired efficient operating parameters were determined.

3. RESULTS AND DISCUSSIONS

The hood analyses investigated the distribution of steam-air mixtures produced by using three different covers simultaneously. Steam-air mixtures at 50°C, 55°C and 60°C were injected into smoke-producing pot models of diameters Ø24, Ø22 and Ø14 cm, respectively. Before looking at the distribution generated according to the current model analyses, the values given for boundary conditions are shown in Figure 6. In the two-phase solution module defined as time-dependent, "air" material was used in the environment and "water vapor" was used for the phase released from the pots to the environment.

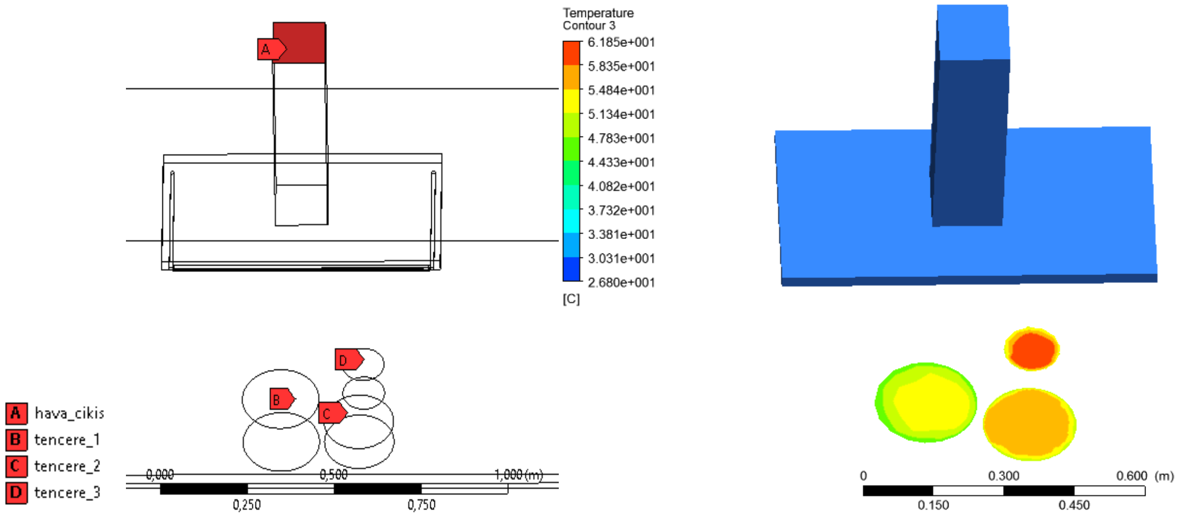


Figure 6. *Boundary conditions for the hood and oven model*

The time-dependent analyses of parameter-driven solution scenarios were performed to compare two different cases (the current hood and the innovative hood) (Table 2). Accordingly, the effect of suction power on the smoke intensity—generated due to the number of covers produced in unit time—was evaluated in terms of diffusion. The validity of the design (being able to respond to users' needs) was tested by examining the diffusion of smoke using time-dependent solutions.

Table 2. *Scenarios and number of covers prepared in unit time*

Scenario	**Furnace No**			**1. Stage**	**2. Stage**	**3. Stage**	**Emitting velocity (m/s)**	**Air Curtain velocity (m/s)**
	1	**2**	**3**					
1 (Model-1)	✓	✓	✓	✓	✓	✓	1	-
2 (Model-2)	✓	✓	✓	✓	✓	✓	1	0.5

The air curtains considered for the hood were developed to provide thermal balance between indoor and outdoor areas, similar to industrial applications. The hood was designed to remove odor and vapor generated by covers without diffusing to the environment. The results obtained were examined with respect to two categories: temperature and molar mass (volume fraction). The temperature parameter was selected to test the change occurring in the environment during emissions from the hoods, while the molar mass was selected to examine changes due to odor and vapor diffusion released from the food. Therefore, efficiency evaluations between Model-1 and Model-2 were made based on these two parameters. In addition, findings were detailed using various representations, such as contour distribution, flow lines and flow volumes.

3.1. Temperature Distributions

In accordance with the boundary conditions specified for the models above, the change in flow volumes due to temperature is shown in Figure 7.

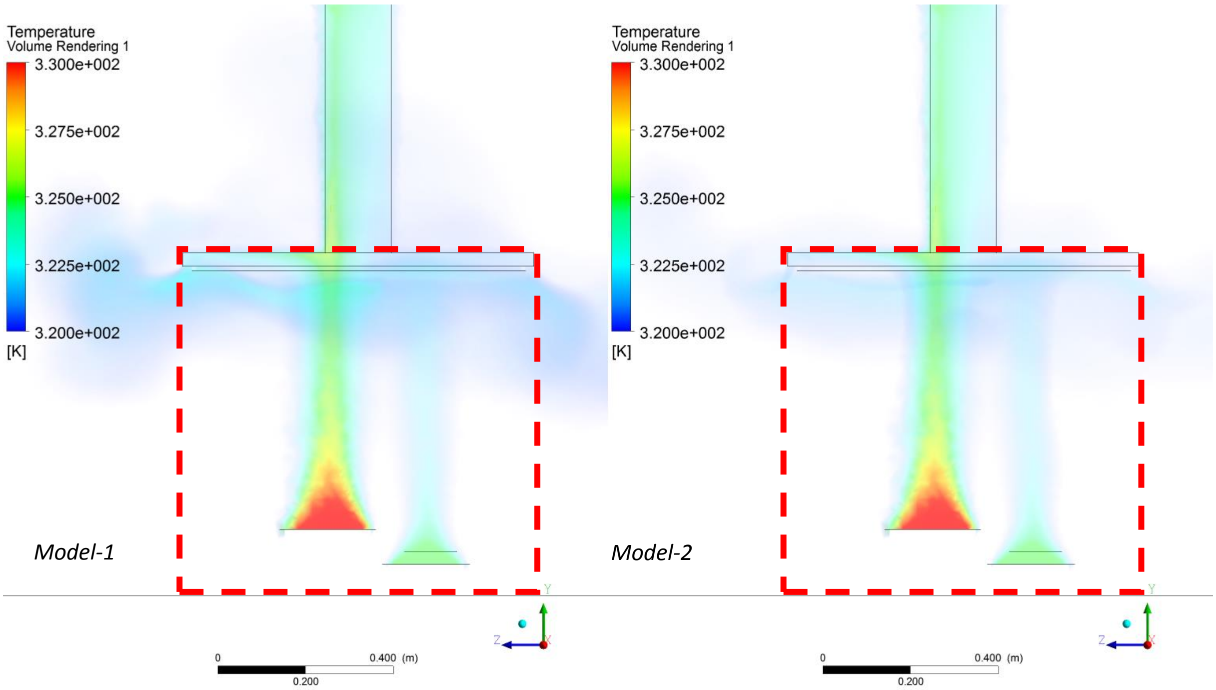


Figure 7. *Smoke distributions diffusing over the oven*

Considering the temperature distribution shown in the figure, it was found that when the hood was operating at full-capacity, it spread over a wider area in Model-1, depending on the number of covers prepared in unit time. In Model-2 it was determined that temperature diffusion was lower than in Model-1, and the temperature generated by the covers was more evenly removed from the environment. However, under the same operating conditions, Model-1 could easily emit the smoke coming from the central axis, but was not be able to emit the smoke flowing over the edges.

Another important point in the temperature distribution is how the temperature generated in the environment changes during cover preparation. Three cross-sections were taken from the kitchen to determine this temperature change, and the comparison was made on the same axis values for both models (Figure 8).

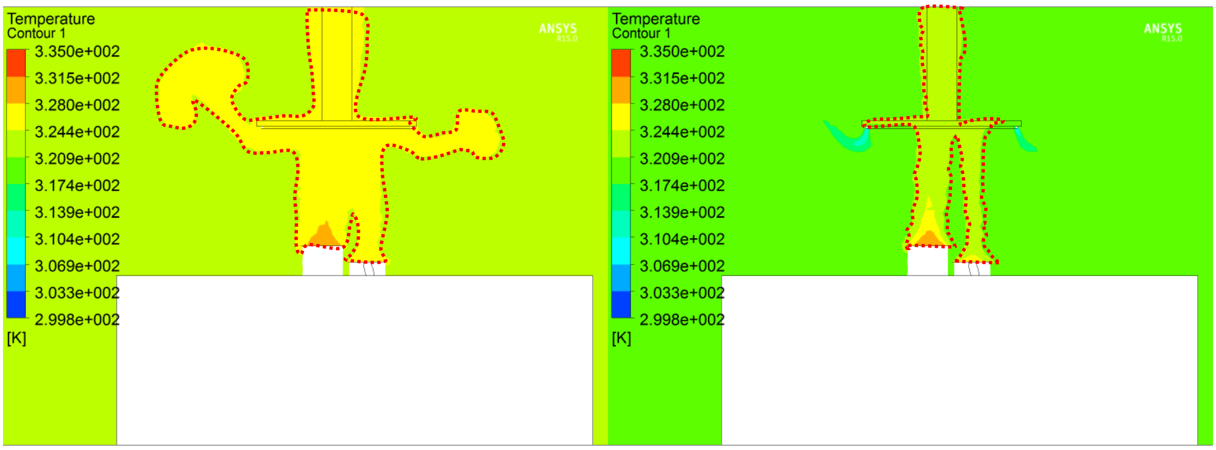


Figure 8. *Temperature distributions in the front section of the kitchen*

Considering the temperature distribution in the front section, it is clearly seen in Model-1 that temperature at the hood edge continues to extend upwards. In Model-1, an expansion of about 2 m occurs over a short period of time. On the other hand, in Model-2, where a curtain of air ducts was formed, it was seen that the temperature change occurred only in the flow area between the oven and the hood (Figure 8).

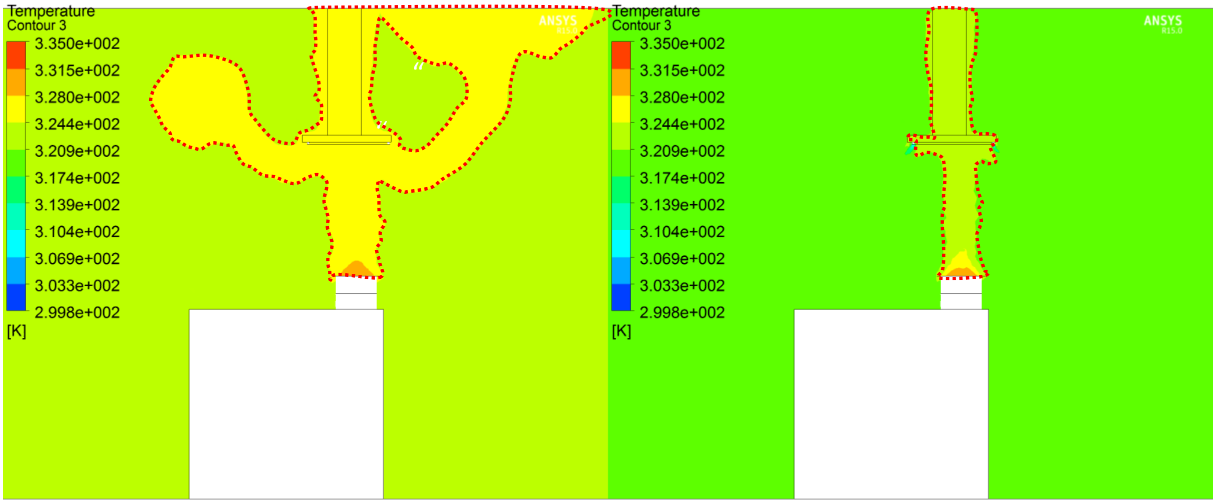


Figure 9. *Temperature distributions in the lateral section of the kitchen*

Considering the temperature distribution in the lateral section of the kitchen, it was observed that the vapor released from the covers spread over a wide area in Model-1. The diffusion area expanded by approximately 2 m, but the suction capacity determined for the hood was not able to fully remove the smoke coming from the covers. In the temperature distribution of Model-2, it is clearly observed that the smoke released from the covers is sent directly to the exhaust pipe with air diffusion prevented by the air curtains (Figure 9).

The top view for the temperature distribution in the kitchen is shown in Fig 10. The distribution generated in the flow field can be seen from this view. In Model-1, the diffusion area was measured at 2x2 m (in x and z coordinates). It can be said that Model-1 cannot sufficiently remove the current temperature gradient, but Model-2 successfully minimizes the distribution effect.

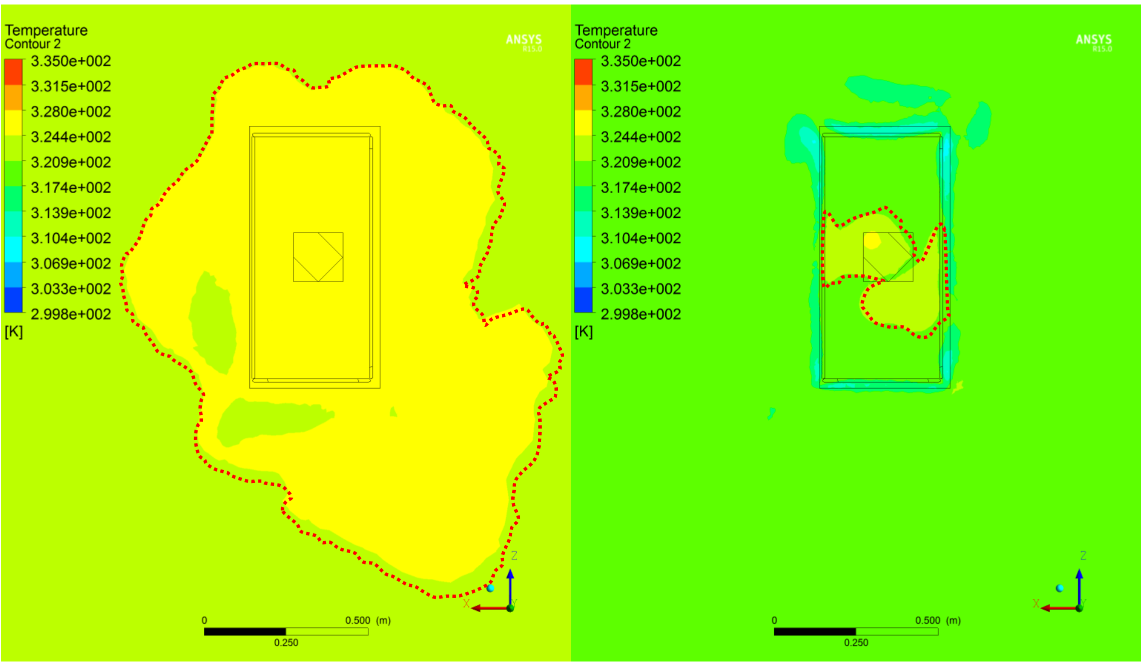


Figure 10. *Temperature distributions for the top section of the kitchen*

Consequently, it was determined that the ambient temperature in the kitchen for Model-1 was approximately 3°C higher than that for Model-2. This was due to the air curtain. Thus, it was clearly observed that the air curtain used in various industrial areas in daily life balanced the temperature distribution between indoor and outdoor areas for this product. Air curtains kept the temperature inside the kitchen at a desired level by removing the odors and smoke diffusing from the indoor area to the outdoor area.

3.2. Smoke Distributions (Mole Fraction)

It was seen that the air curtain channels on the hood were successful in preventing increasing temperature distribution. It is also known that odor originating from covers reduces the quality of life in both kitchens and other living spaces in houses. It is very important to select a variable to represent the smoke or odor diffusion in the flow analyses so that the models constructed can produce results for these parameters. In this study, multiphase flow modeling was used to test the density variation caused by the different phases. Based on the solutions obtained, the distribution in molar mass was visualized by associating it with smoke and vapor.

It is seen in Model-1 that the smoke produced from covers diffused from inside the hood into the kitchen because it could not be removed from the hood (Figure 11). The vast majority of the vapor phase was removed, but 10% of it spread into the kitchen.

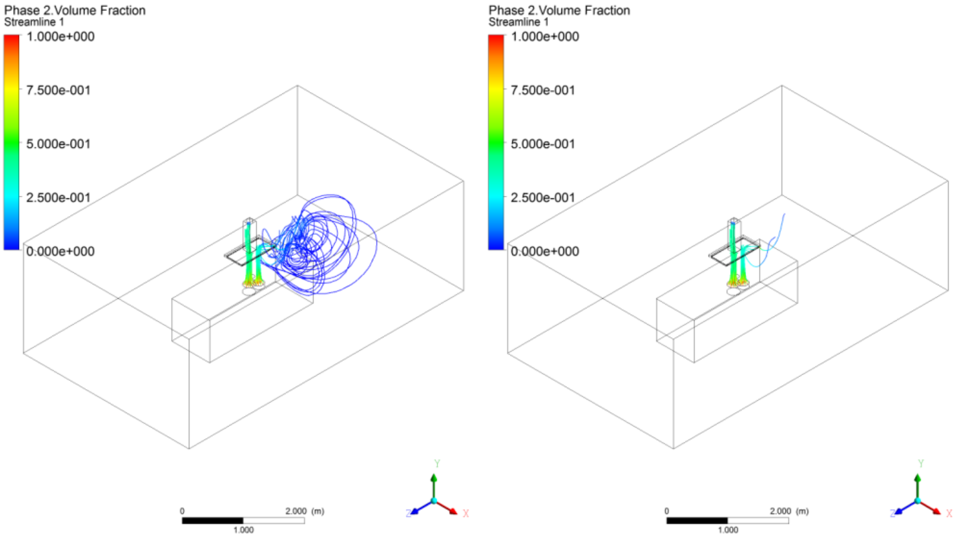


Figure 11. *Smoke distributions inside the kitchen*

Considering the smoke distribution shown in Figure 11, it is seen that when the hood is operating at full capacity, smoke diffuses along flow lines into the space in Model-1. It was determined that for Model-2, odor diffusion hardly occurred at all, and the smoke distribution generated was evenly removed from the environment. Under the same operating conditions, it was observed that the intensity of the air curtain kept the smoke within the volume of the hood during the changing phases (Figure 12).

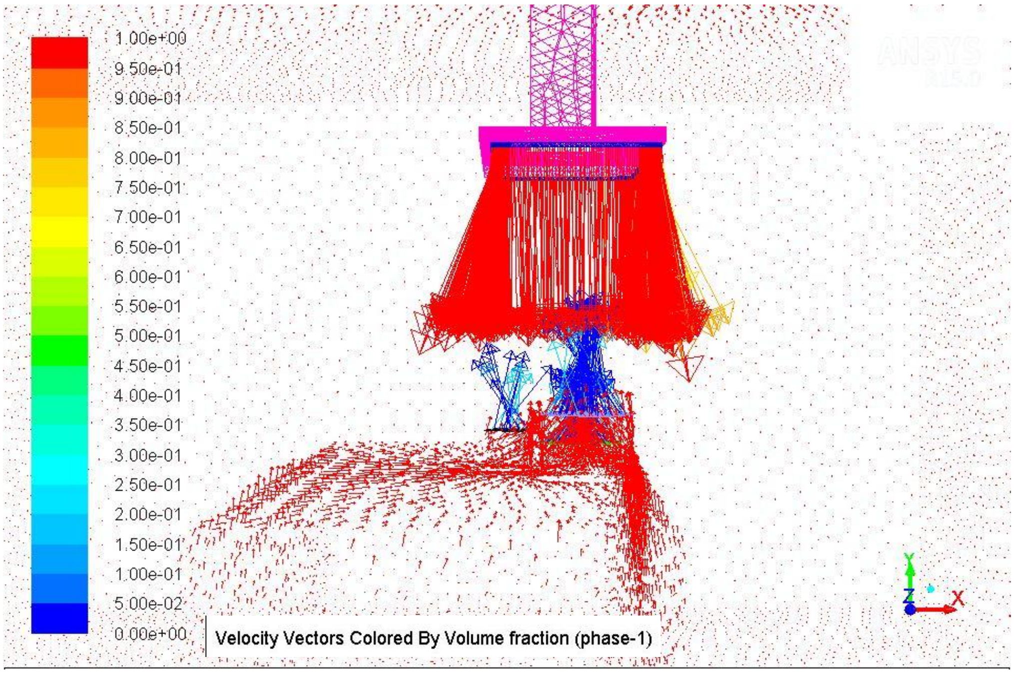


Figure 12. *Air curtain in the lateral section and the smoke diffusion (Model-2)*

Figure 12 shows the vector distribution caused by the air curtain for the phase difference between the oven and the hood. Steam released from covers is trapped inside the air ventilated by the innovative air ducts and prevents diffusion into the environment. Thus, energy saving is achieved by establishing thermal equilibrium, and smoke and odor diffusion is prevented. From this point of view, it is clearly seen that the idea of an air curtain produces positive results.

4. CONCLUSIONS

The issue of smoke and odor diffusion in the kitchens was addressed this study in terms of current hood characteristics. For this purpose, current case analyses were carried out, design suggestions were considered. In this regard, in addition to suggestions for a physical curtain, a design based on preventing smoke and odor diffusion by reverse air flow was proposed, since air produced by an air-flow suction system can also produce an air curtain.

It was proposed to improve this functionality using step-by-step repetitive simulation experiments based on a functional-based hood design and the application of a developmental design approach. Since the use of air curtains in industrial applications could be modified to be hood-specific, this aspect of product design was examined. Results obtained from CFD analyses showed how the current type of design performs in keeping smoke, temperature and odor in a volume of air flow between the cover and the hood. Trials delivered positive results in terms of temperature distribution and prevention of smoke diffusion. An innovative model for smoke and odor diffusion—about which users frequently complain—was subsequently designed. It can be said that the air channels that were developed improved the temperature distribution balance and improved users' requirements regarding odor diffusion.

As can be seen from the hood example, supporting industrial design processes with developmental models can provide very significant new innovations and results. The simulation and calculation process provides an equivalent effect to prototyping—one of the most fundamental aspects of a design. Under the scope of this study, computer-based experiments—instead of the physical phenomenon of prototyping—were effective in making progress with this design.

CONFLICT OF INTEREST

No conflict of interest was declared by the authors.

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