Numerical Simulation Study on Transpired Solar Air Collector

Chongjie Wang Zhenzhong Guan Xueyi Zhao Delin Wang
Professor Professor Professor
Shandong Jianzhu University
Jinan, P. R. China; 250101
delinw@msn.com

Abstract: The unglazed transpired solar air collector is now a well-recognized solar air heater for heating outside air directly. In this article, researchers introduced numerical simulation tools into the solar air collector research area, analyzed the performance characteristics of the unglazed transpired solar air collector and compared them with several kinds of traditional solar air collectors. The results showed that the unglazed transpired solar air collector has unparalleled advantages in the ventilation preheating area and also proves that CFD tools have their own advantages in the solar air collector research area.

Key words: solar air collector; transpired; UTC; CFD; simulation

1. INTRODUCTION

Solar heat utilization is now the most mature, economic form among all the forms of solar utilization, and has the nearest relationship with buildings. As the main equipment of solar heat utilization, solar air collector use air as the heat carrier, has a wide range of operating temperature, low requirement of airproof, high toggle speed, low cost and maintenance. It can be used in the fields of space heating, outdoor air preheating, agricultural drying, etc. Especially because of its low cost, it can be popularized in the countryside and underdevelopment area, which made it the most suitable form of solar heat utilization.

Through over 100 years’development, solar air collector has developed many types, according to the construction of the absorber plate, solar air collector can be divided into two main types: transpired collector and untranspired collector[1].

Untranspired collector is now the most widely used collector, its principle is quite simple: the sunshine irradiate on an untranspired absorber plate, air is heated by the absorber when flowing over the absorber. Its construction is very simple, but the heat transfer between air and absorber is not so good. In this type of collector, heat transfer took place on the surface of the absorber plate, part of the radiant heat is reflected back to the space, on the other hand, because the coefficient of convective heat transfer between air and the absorber plate is quite low, the temperature of the absorber plate is high, radiation loss is quite large. In order to strength the heat transfer, we can take some measures such as add fins, improve the shape of the absorber plate, the heat effectiveness can be limited increased.

Transpired solar air collector is a new type of collector that developed on the boundary layer theory for only over 10 years. The absorber of the transpired solar air collector is always composed with perforated plate or wire netting, which can effectively strengthens the absorb of the solar radiant heat and the heat convection between air and the absorber, so it has a better thermal characteristics than untransp-ired collector. In addition, unglazed transpired solar air collector has many advantages such as: very simple construct, lower cost, easily installation, better integration with buildings and can heat outside air directly, etc. It is very suitable for outdoor air prehea -ting and drying and has a very good popularize foreground.

Fig.1 shows the construct of the unglazed transp- ired solar air collector(UTC——Unglazed Transpired Collector). UTC is composed with frames,

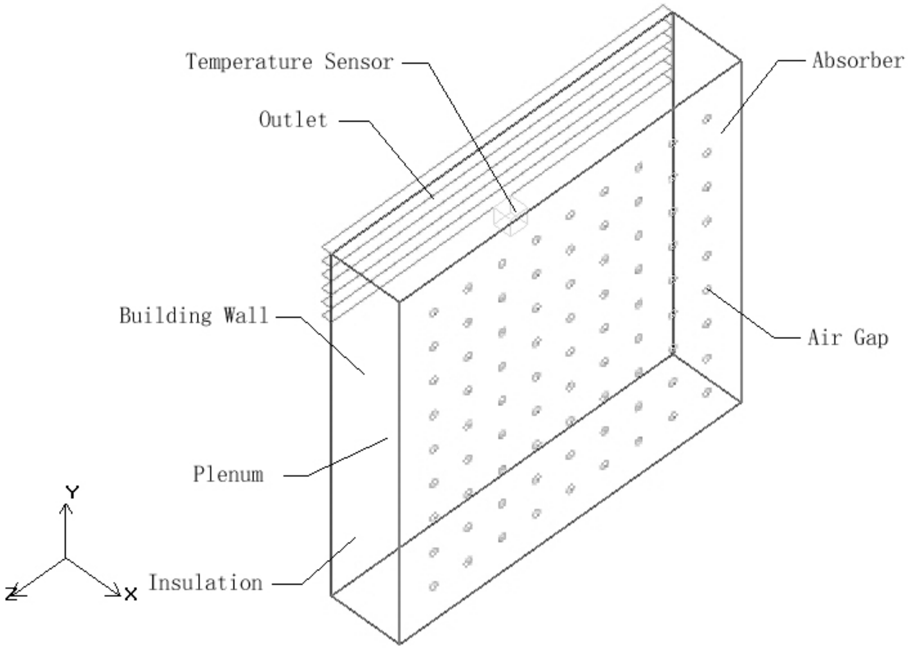

Fig.1 Unglazed Transpired Solar Air Collector

perforated absorber, fan, temperature controller, insulation, etc, installed on the outer wall of buildings. There is a plenum between the absorber and the building wall, on the top of the plenum there is an outlet opened on the wall and connected with an blowing fan by air pipes, a temperature sensor is installed at the outlet. After sunrise, as the radiant intensity increased, the temperature of the absorber increased, then the air in the plenum is heated by the absorber, when the air temperature reaches the set point, the temperature controller starts the blowing fan and forms negative pressure in the plenum, so outside air is indrafted into the plenum and heated during through the air gap on the absorber plate, then hot air is delivered by air pipes to the place where heat is needed. This shows that UTC has two main characteristics:

1)Simple Structure.

Because there's no glazing parts, UTC has very simple structure, low cost, conventionally installation and almost no maintence.

2)Heat Outdoor Air Directly.

Different from other types of solar air collector, UTC heat outdoor air directly which is very suitable for Indoor Air Quality Improvement and Crop Drying.

Then on the bases of the thermodynamics analysis we'll use the CFD tools on the study of the solar air collector, optimize the characteristic and parameters of the collector and compared UTC with the tranditional plate collector and the unglazed untranspired collector[2].

2. ADVANTAGES OF THE NUMERICAL SIMULATION ON SOLAR AIR COLLECTORS

In traditional, during solar air collector (system) designing, designers always do the designing and product developing work all by their experience and simply theoretical analysis. It always take much time or lower in precision. For example, on the choice of the wideness of the plenum of the Trombe Wall, people always choice 150mm～200mm according to the experience, but if this dimension is optimal is still lack of quantitative analysis. Obviously, it's unpractical to carry out a theoretical analysis or experimental study in every single project or heat collecting system. Computational Fluid Dynamics (CFD) has changed the traditional design process. Because CFD program can show the detail of the flowing and heat transfer of the fluid, so it can not only predict the collectivity performance of the solar air collector(system), but can also easily find the problems of the product or project design by flow field analysis. So the use of CFD tools can broaden the research field and strengthen the research profundity at the same time[3].

The use of CFD tools made many of the

"experiment samples" done by computer, that is to form many types of "dummy experiment samples" by the CFD program and and compares them dummy in computer. It can effectively reduce the experiment workload. The select of the precept is based on scientific analysis, so it's easily to insure the success of the design and the stabilization of the product quality. People can predict the performance before real experiment research, so the cost of research can be reduced, the success ratio and research efficiency can be increased. In addition, CFD can intensify the research profundity of solar air collector, by simulation, we can see the inner flow field and temperature field intuitionisticly which is much more detailed than the experiment research. On the bases of CFD simulation, we can do better improvement on the structure of the collector. Use the tracing function of CFD tools, we can even predict the ash deposit of the transpired collector and improve on the corresponding aspect.

3. NUMERICAL SIMULATION RESEARCH ON UTC

3.1 Blowing Fan Shuts Down

Firstly, we carried on a simulation on UTC which blowing fan is shut down in order to see the performance of UTC working with natural thermal pressure. The heat collection area of the model is 1m×1m, the width of the plenum is 200mm. The radiant intensity is 1000w/㎡, outdoor temperature is 0℃, part of the simulation results is shown as fig.2.

By simulation, we know better about the flow and heat exchange characteristic of UTC, which can be concluded by the following three points:

The heating process of UTC is mainly centre at the air gaps of the transpired absorber plate, as the hot air flows upwards in the plenum, air temperature rises little. The temperature gradient along vertical orientation is smaller than the glazed flat collector and unglazed untranspired collector.

Negative pressure is the main drive of UTC which indraft outside air into the plenum. By the simulation of the pressure field in the plenum, we may found that negative pressure decreases along with the rise of height, and form a neutral plane on the top of the plenum near the outlet of UTC where the pressure turns to positive pressure. The velocity of flow decreases along with the fall of negative pressure, when it comes into the positive pressure area, the air is not indraft into the plenum but blown out of the plenum. In addition, as a result of the pressure difference, there's a little flow backwards in the outlet, which means the width of the plenum is a little too big, so reduce the width of the plenum or turn on the blowing fan should solve these problems.

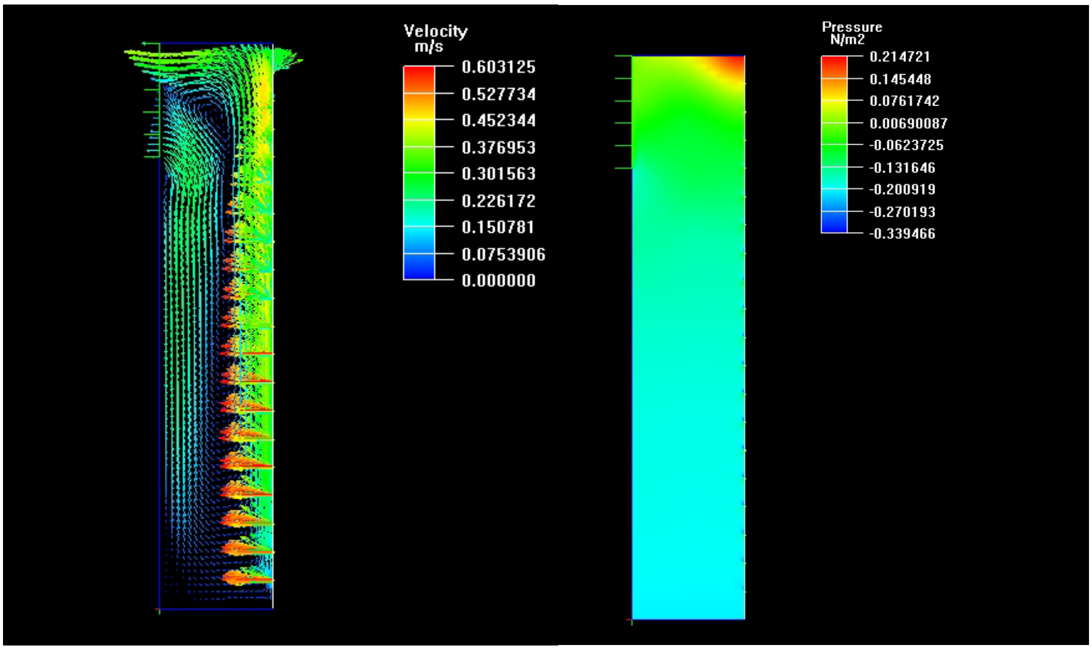

Fig.2 Part of the simulation results

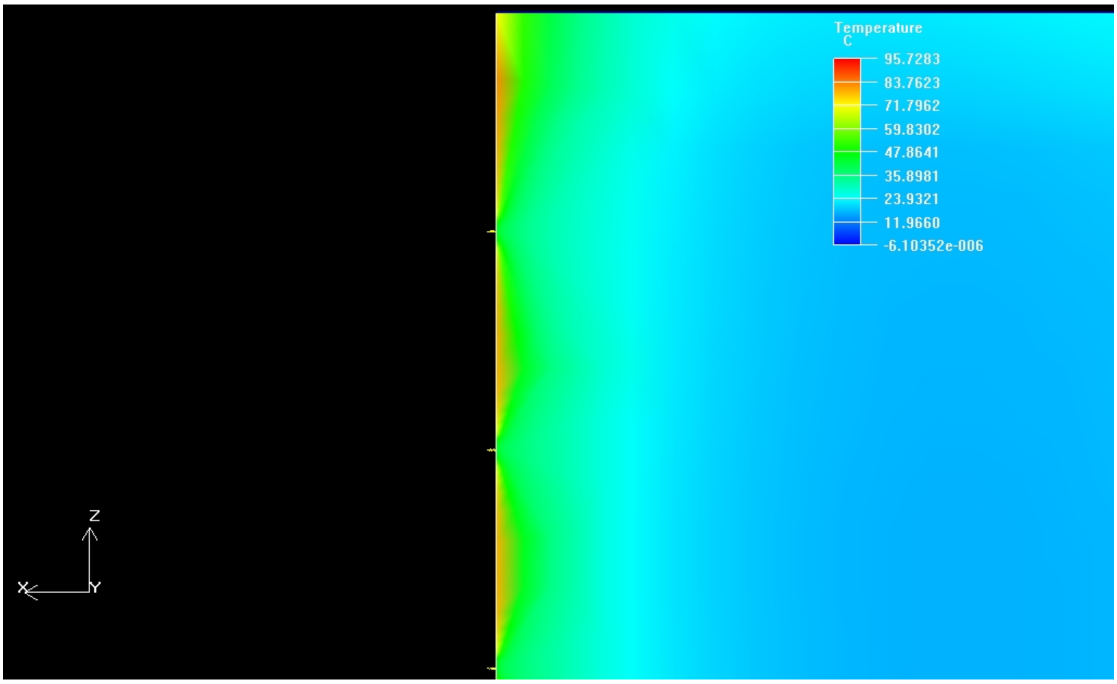

Fig.3 The temperature field near the inner surface of the absorber plate

In the area that press close to the inner surface of the absorber plate, the air velocity is very low, which forms a comparably stagnant boundary layer. In the boundary layer, hot air flows very slow and "obturated" by the air flow through the air gap. (Fig.3) The heat in this area is hard to change timely which is disadvantage to the improve of the effectiveness, so proper measures should be taken(for example change the shape of the air gap or the absorber plate) to avoid the form of the boundary layer.

By analyzing the results of the simulation, we can get the temperature field and velocity field of the collector. Then we can calculate the mass flow rate and Quantity of heat provided by UTC:

$$m = vF\rho \tag{1}$$

$$Q = mC_p\Delta T \tag{2}$$

m——Mass flow rate;

Q——Quantity of heat provided by UTC;

v——Average folw velocity;

F——Effective cross sectional area;

ρ——Air specific votume at constant pressure 1.4kg/m³;

C_p——Air specific heat at constant pressure 1005J/(kg·K);

ΔT——Temperature difference between heated air and outside air;

The effectiveness η can be calculated by:

$$\eta = \frac{Q}{Q_s} \tag{3}$$

Q——Quantity of heat provided by UTC;

Q_s——Quantity of radiant heat received by UTC;

We had built two models with different plenum width (200mm and 50mm) in order to compare the width's affect to the effectiveness. The effectiveness of the 200mm wide model and 50mm wide model is 0.7 and 0.72, this shows that because the heat exchange process mainly took place at the air gaps of the absorber plate, the width of the plenum has little affect on effectiveness.

3.2 Compared with the Traditional Solar Air Collector

Table 1 shows the effectiveness of different solar air collector under the same boundary condition:

Tab. 1 Effectiveness of different types of solar air collector

TYPE	FLAT COLLECTOR（plenum200mm）	FLAT COLLECTOR（plenum50mm）	UNGLAZED UNTRANSPIRED COLLECTOR（plenum200mm）	UNGLAZED UNTRANSPIRED COLLECTOR（plenum50mm）	UTC（plenum200mm）	UTC（plenum50mm）
η	0.51	0.788	0.47	0.62	0.7	0.72

From table 1, we may see that under fresh air operating mode, UTC has higher effectiveness than flat collector and unglazed untranspired collector, and can be further improved. Consider its very low cost and no maintenance, UTC has unparalleled advantages in the field of solar heating outdoor air directly.

3.3 Flow Rate’s Effort on Effectiveness

In engineering applications, UTC is working with blowing fans, in order to investigate the effort of the flow rate to the effectiveness, we took a series of simulation. (Fig.4) The model is similar with 3.2, the width of the plenum is 200mm, the porosity is 1.12% and the flow rates are 36m³/h, 45m³/h, 90m³/h, 135m³/h and 180m³/h. The results is shown below(Fig.5～Fig.6):

From Fig.5 and Fig.6 we can see that as the flow rate increased, the temperature of heated air decreased and the effectiveness increased. When effectiveness reached nearly 0.8, the curve turns gentle, increased little with the increase of flow rate. Then we may keep a balance of the temperature and effectiveness according to the requirement of the project.

3.4 Radiant Intensity’s Effort on Effectiveness

In order to design a proper UTC system in a

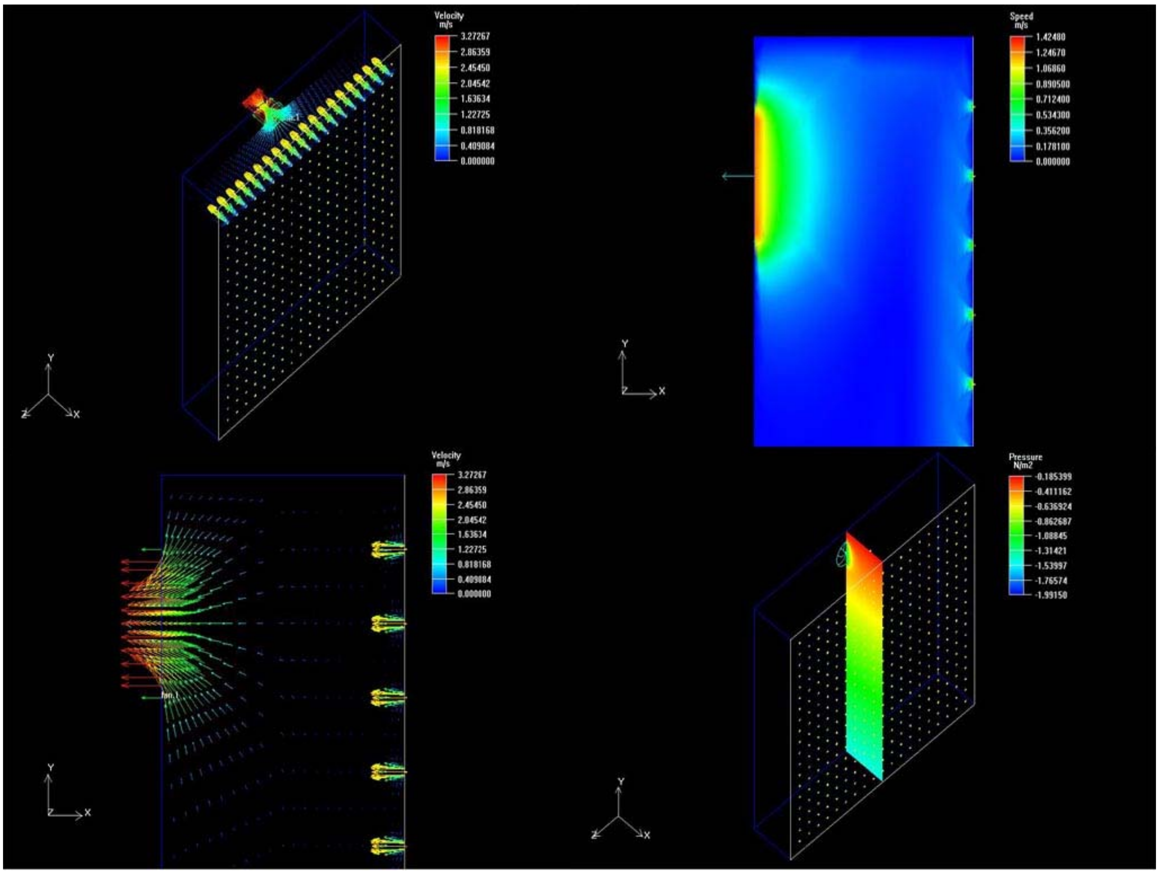

Fig.4 Simulation of different flow rate

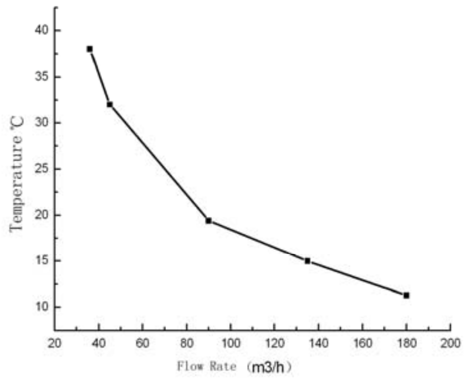

Fig.5 Plots of simulation results in the form of Temperature vs. Flow rate

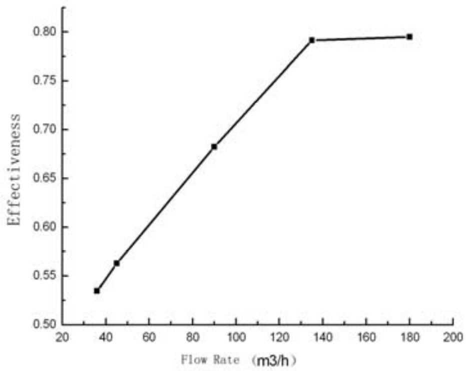

Fig. 6 Plots of simulation results in the form of Effectiveness vs. Flow rate

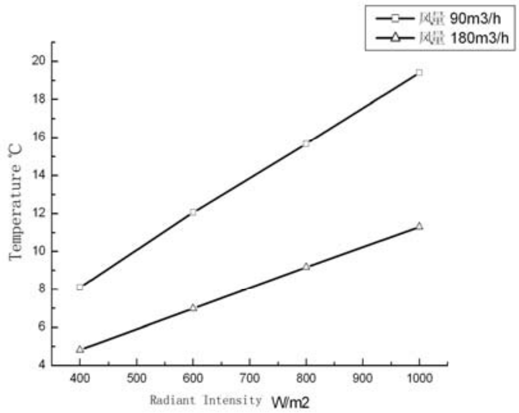

Fig. 7 Plots of simulation results in the form of Temperature vs. Radiant Intensity

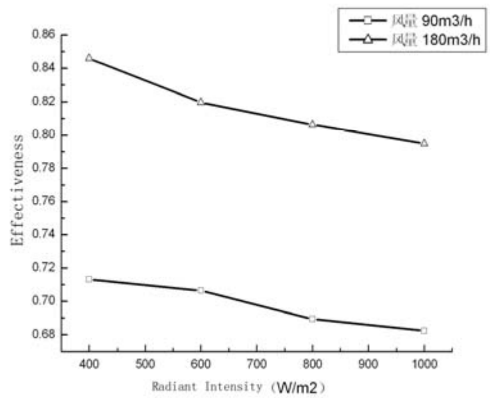

Fig.8 Plots of simulation results in the form of Effectiveness vs. Radiant Intensity

certain latitude, we investigated the effort of the radiant intensity to the effectiveness, we carried on a series of simulation. The model is similar with 3.3, the width of the plenum is 200mm, the porosity is 1.12% and the flow rate is 90m³/h, the radiant intensity is 400W/㎡, 600W/㎡, 800W/㎡, 1000W/㎡. The results is shown below(Fig.7～Fig.8):

From Fig.7 and Fig.8 we can see that as the radiant intensity increased, the temperature of heated air increased, but the effectiveness has almost no change. It means that effectiveness is the own property of UTC, only has relationship with the structure and working parameter, and is foreign to radiant intensity. Therefore, static experiment which radiant intensity is constant can also get satisfactory results.

4. CONCLUSIONS

In this article, we make comparative analysis of several types of solar air collector with numerical simulation tools, got several important conclusions, validated the advantages of UTC in ventilation preheating field and investigated the flow rate and radiant intensity's effort to the effectiveness. The results shows that CFD tools has its own advantages in the field of solar air collector research, it's a powerful assistant tool for researching and is worth to apply in more abroad fields.

REFERENCE

1. XinshiGe, HongYe. Solar air heating system[J]. Solar Energy, 2003,1:13-14. (In Chinese)
2. Biona M , Culaba A. Serafica E, Del Mundo R. Performance Curve Generation Of An Unglazed Tranpired Collector For Solar Drying Applications.http://www.retsasia.ait.ac.th/Publications/WRERC%202005/UPD-paper1-WRERCE05-final.pdf

3． Keith Gawlik, National Renewable Energy Lab Uses CFD to Develop Low-Cost, Solar Collector http://www.fluent.com/solutions/articles/ja087.pdf