

A STUDY OF WIND PRESSURE COEFFICIENT AND ITS EFFECT ON CROSS VENTILATION - CFD WITH A REPRESENTATION OF MOUNTAIN UNDULATIONS-

Yaudaki Sumida¹, Koji Sakai¹, and Hiroki Ono¹
¹ Meiji University, Tokyo, Japan

ABSTRACT

For the purpose of revitalizing traditional architecture, we considered the characteristics of a traditional architecture cluster with regard to cross ventilation, and from an environmental engineering point of view, we proposed techniques to improve the surrounding environment. In this report we make use of and improve the urban area model used in a prior report, as well as use CFD to take into account the effects of surrounding topography. To improve the urban area model, we make detailed computations of the wind pressure coefficient distribution. Second, we reproduced in more detail the shape of the target residence, and performed a detailed analysis. From this result, we analysis related to the internal wind speed of the target residences.

INTRODUCTION

In many places in Japan there remain clusters of traditional architecture, but, as life styles change, demolitions show increasing or decreasing trends. For the preservation of such traditional architecture, and for the purpose of revitalizing it, we consider the characteristics of a traditional architecture cluster with regard to cross ventilation. We also, with regard to the various characteristics of traditional architecture clusters, looked at techniques for improving the surrounding environment. In an earlier report, there was a survey of the thermal boundary for a single wind direction (southerly) for existing urban houses (Residence A and Residence F) in Takahashi City, Okayama prefecture. In this report, we improve the urban area model used in the earlier report. The CFD was expanded to include 16 wind directions and for residences A and F the wind pressure coefficient distribution was computed. Furthermore, in order to perform a more detailed analysis, the shape of the mountains in the vicinity of Takahashi City was taken into account when creating the inflow boundary conditions, the reproduction of the target residences' environs were improved, and the building interior cross ventilation characteristics were examined.

IMPROVED URBAN AREA MODEL CFD

Analysis Summary

Fig. 1 shows the vertical mesh partitions for the urban area model used for this analysis. Likewise,

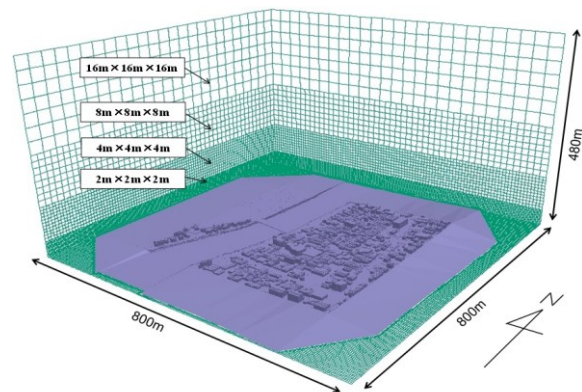


Fig.1 Refinement of Urban Area Model

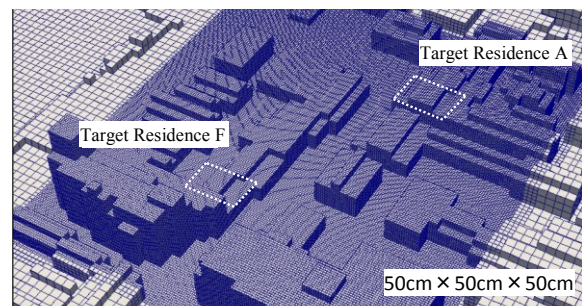


Fig.2 Around the Target Residence

Tab.1 Analysis Condition of OpenFOAM.

Total number of Cell	3,179,195
Turbulence model	Standard k-ε model
Solution of pressure	SIMPLE
Finite difference Scheme for convective terms	TVD (vanLeer limiter)
Boundary condition of wall surface	Generalized log law
Condition except inflow surface	Boundary condition of pressure
Analysis wind direction	16 directions

Tab.2 Calculation Formula of Inflow Boundary Condition.

$$u_z = u_s \times \left(\frac{z}{z_s} \right)^\alpha \quad \dots (1) \quad \varepsilon_z = C_\mu^{0.5} k_z \frac{u_z}{z_s} \left(\frac{z}{z_s} \right)^{(\alpha-1)} \quad \dots (2)$$

$$k_z = \frac{\sigma^2 u_z^2 + \sigma^2 v_z^2 + \sigma^2 w_z^2}{2} \equiv \sigma^2 u_z^2 = (I_z \times u_z)^2 \quad \dots (3)$$

u_z : vertical profile of inflow wind velocity, u_s : wind velocity of reference height, z_s : exponential of the power law (Roughness classification of the surface of the earth in Takahashi City is III, $\alpha=0.2$), I_z : turbulence intensity, k_z : energy of turbulence, σ : standard deviation of wind speed fluctuation, ε_z : vertical profile of dissipation rate, C_μ : factor of proportionality=0.09

Fig. 2 shows the mesh partition used for the environs and residential structures around residences A and F.

The urban area model used for this analysis was generated using a random group of points approximately every 2 meters that were a sampling of discrete elevation points from Digital Surface Model (DSM) data, provided by the Kokusai Kogyo

Company. The mesh was created by using the load balancing parallel mesh generation utility, snappyHexMesh, which is bundled with OpenFOAM (v2.1).

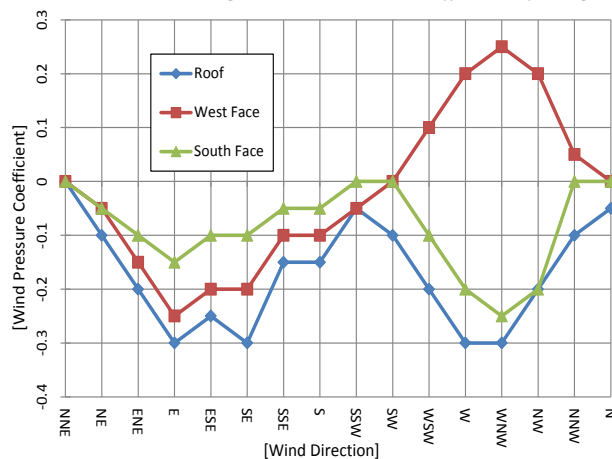
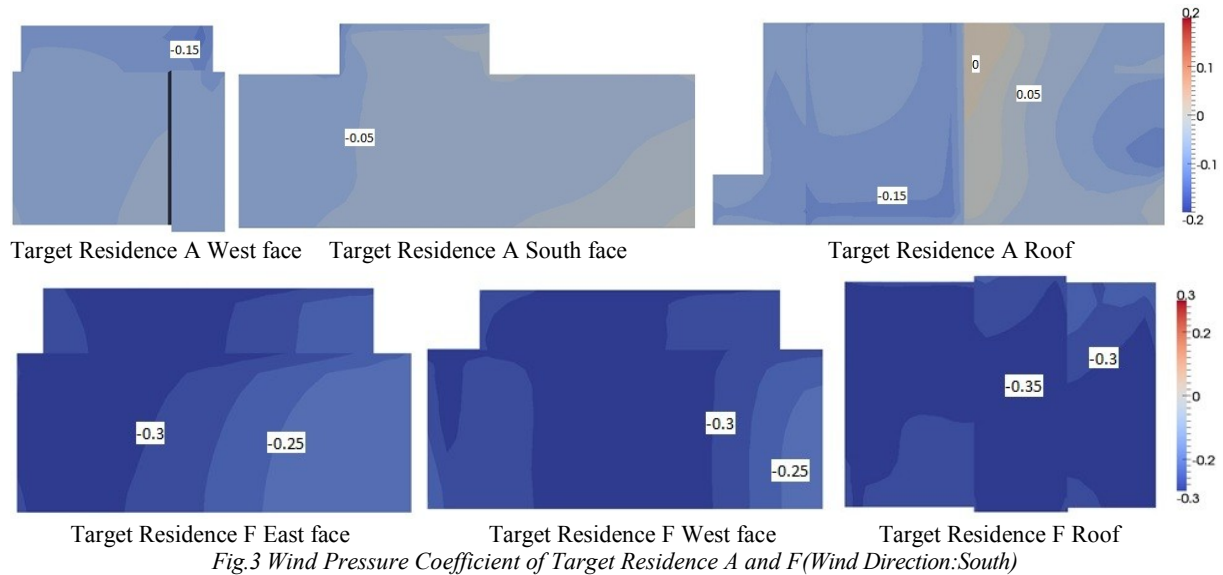


Fig.4 Wind Pressure Coefficient of Target Residence A

The traits of the traditional architecture clusters, such as the gabled roofs and so forth, were reproduced by using block shapes to approximate them. Also, although there are mountains to the Northwest of Takahashi City, from the viewpoint of this analysis, the mountains are omitted in Section 1 because of some uneasiness regarding the resolution of their calculations.

In the vertical direction, the analysis domain used boundary layer thickness standards from the Architecture Institute of Japan's "Recommendations for Loads on Buildings" provisions. The horizontal unit of measurement for the analysis domain is inferred from the outer edge of the urban area, and extends up to 5 times the height of a typical building. From all this, the size of the analysis domain was set to 800m front to back by 800m side to side, with a height of 480m. The maximum mesh unit in the vicinity of

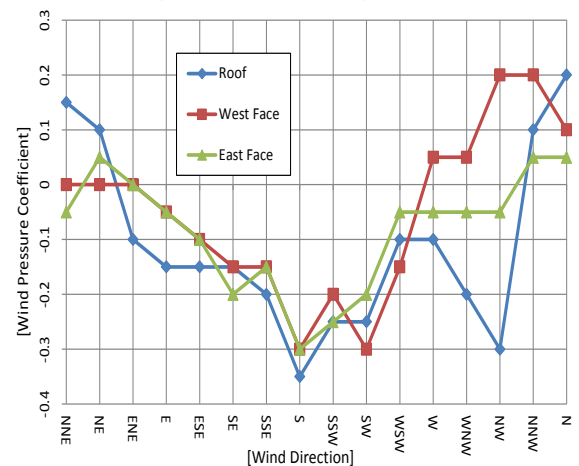


Fig.5 Wind Pressure Coefficient of Target Residence F

the sky is 16m, and in the vicinity of ground surface plane the mesh is 2m. In the vicinity of target residences A and F, the mesh size is 50cm.

The calculation formula for the turbulence wind speed, turbulence kinetic energy, and energy dissipation rate used for the inflow boundary conditions were calculated from the equations given in Tab. 2. In these calculations, Takahashi City has a ground surface roughness calculation of III with a power multiplier of 0.2, a vertical inflow wind velocity profile of 480m, and using the reference ground point of 6.6m from the Expanded AMeDAS Weather Data for Takahashi City the wind velocity is 2.0m/s. In this analysis, for the purpose of understanding cross ventilation around the target residence, the thermal & meteorological effects are not included. Other analysis conditions are shown in Tab. 1.

Analysis Results

Fig. 3 shows a diagram of the wind pressure coefficient distribution for residences A and F. As a typical example, the results are given for southerly winds, the primary wind direction for Takahashi City. For Residence A, changes in the wind pressure, for the most part, cannot be seen.

For Residence F, negative values are shown for all wall surfaces due to the effects of other structures in the vicinity.

Fig. 4 shows, for Residence A, the wind pressure coefficient for each wind direction at the center point of each wall surface. For Residence A, for wind directions of E, ESE, SE, as well as WSW, W, WNW, NW, it can be seen that the variation in the wind pressure coefficient for each wall surface had a tendency to become larger. Also, the wind pressure coefficient for wind directions of SW~NNE impacting the West wall became extremely large. It was considered that was due to omitting the mountains to the West of Takahashi City for the purpose of resolving the calculations.

Fig. 5 shows, for Residence F, the wind pressure coefficient for each wind direction at the center point of each wall surface. For wind directions of NNE~S, the differences in wind pressure coefficient between each wall surface had a tendency to become smaller, so it is thought that it does not show the promise of cross ventilation from outside winds. This is presumed to be caused by the attenuation of the wind in the large number of upwind structures. For wind directions of W~NNW, the wind pressure coefficient for West side wall surfaces shows positive values, but the East facing walls show negative values. Since, for wind directions of WNW, NW, the difference in the wind pressure coefficients for the walls is particularly large, it is thought that it shows the promise of cross ventilation through openings.

CFD TAKING INTO ACCOUNT THE EFFECT OF SURROUNDING TOPOGRAPHY

Purpose

In Section 1, the urban area mesh used in the CFD of the previous report was improved for this analysis. However some problems remain because, in order to resolve the calculations, some points on the mountain peaks were ignored, the roofs were reproduced by approximating them with block shapes, and so forth.

Okayama Prefecture is surround by mountains, and the strengthening of the wind turbulence within the city area due to the effects of the mountain topography is considered to be quite complex. The mountain topography, which was ignored in the CFD mentioned in Section 1, as well as the effect of the surrounding mountain topography for on the order of several km, need to be considered. Also, the DSM data used for

the reproduction of the residences' shape uses a random sampling of point groups with an interval of about 2 meters. However this level of reproduction is not adequate because residential openings ranging in size from 2~3 meters are common within the area of the target city.

So, in this section, we considered the topography of the surrounding mountains when creating the inflow boundary conditions and improved the reproduction of the shape area around Residence A, as well examined it in relation to interior cross ventilation.

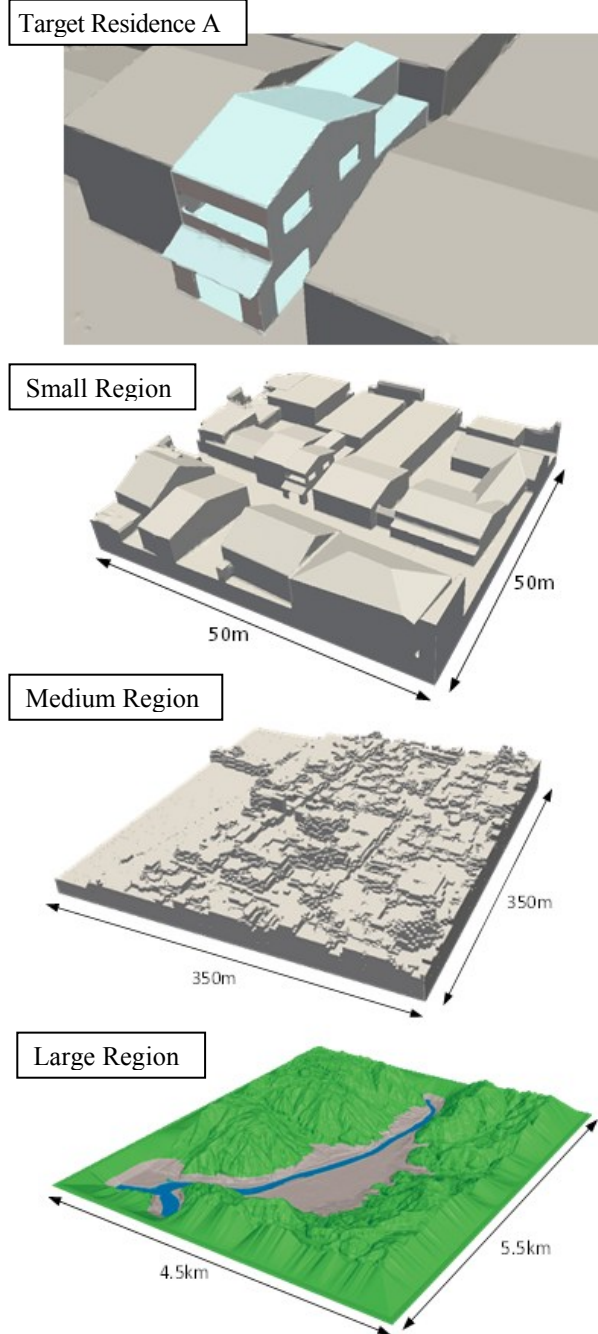


Fig.6 Computational Region

Domain Setting

In order to create the inflow boundary conditions while taking into account the mountain topography, as shown in Fig. 6, the calculation domain is considered to be partitioned into 4 regions.

1. Target Residence A
To hollow out the interior, the points for the actual locations of openings in Residence A were established. In this report, interior floor plans and so on were omitted.
2. Small Region
Centered on the target residence, 3~4 structures were included in a region approximately 50m on each side. The shape of the structures is based on inspection of the actual site; the slopes of the roofs were also reproduced.
3. Medium Region
With the small region placed in the center, this region is about 350m on each side. The shape data for this region was created from the urban area model used in Section 2 and similarly from DSM data. The roofs and so forth were approximated with blocks in units of 2m.
4. Large Region
With the medium region placed in the center, the large region is 4.5km in the East-West direction and 5.5km in the North-South directions. This region was created from elevation value data (5m interval) generated by the Geospatial Information Authority of Japan. The surface was reproduced, but obstacles such as buildings and so on were not. This was done to resolve the calculations and simplify the setting of the inflow boundary conditions around the periphery of the region.

First, calculations were performed only for the larger region. From those results the boundary surface, turbulence kinetic energy, and energy dissipation rate were derived for the medium region. Using these as boundary conditions, calculations were made for the medium region, and from those calculations were made for the small region. Residence A was included in the small region.

Analysis Summary

Fig. 7 show the calculation mesh for the small and medium regions. The mesh was created by using the load balancing parallel mesh generation utility, snappyHexMesh, which is bundled with OpenFOAM (v2.1). The large region ground surface plane incorporates three layers with an average thickness of 0.35~1.7m, with the mesh size increasing in steps with distance from the surface up to a maximum mesh of 25m. The medium and small regions have a mesh of about 0.08m in the vicinity of the target residence, in other places, the mesh increases in steps up to a maximum of 5m. The number of cells for the large region is 70,149,414, and for the medium and small region is 6,327,905. Analysis conditions are shown in Tab. 3.

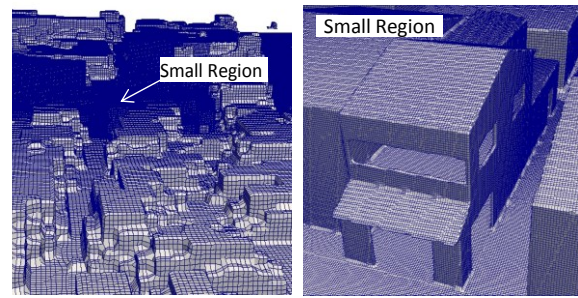
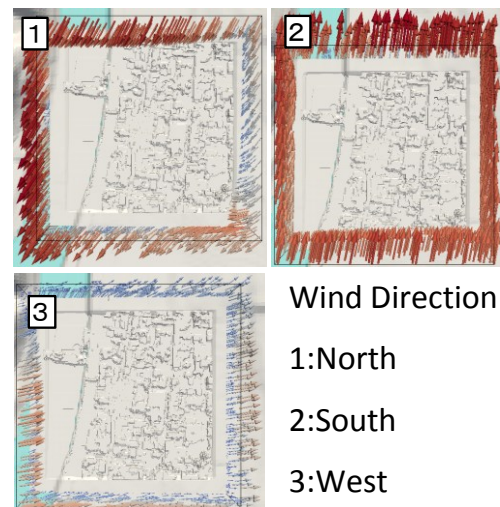


Fig.7 Mesh Partitioning of Medium Region and Small Region

Tab.3 Analysis Condition of OpenFOAM.

Number of cells for the large region	70,149,414
Number of cells for the medium and small region	6,327,905
Turbulence model	Standard k-ε model
Solution of pressure	SIMPLE
Finite difference Scheme for convective terms	TVD (vanLeer limiter)
Boundary condition of wall surface	Generalized log law
Condition except inflow surface	Boundary condition of pressure
Analysis wind direction	3 directions(North ,South,West)



Wind Direction
1:North
2:South
3:West

Fig.8 Boundary Condition of Medium Region

Analysis Results

In the large region, we performed the calculation by inserting a uniform wind influx from the South. For this wind influx, we referred to Japan Meteorological Agency wind speed statistical data⁶⁾ for Yonago City. In the vertical direction we used a roughness length of $z_0=1[m]$ distributed according to a logarithmic scale from the calculated results for the large region, we derived the boundary surface for the medium area as shown in the calculated results in Fig.8. The wind influx in the large region had a uniform speed, but we confirmed a turbulent state when the effect of the shape of the mountains was included.

Fig 9 shows the wind condition in the vicinity of Residence A for the case where the wind direction is to the South. We were able to confirm that the wind flows into and flows out of Residence A.

Fig. 10 shows the air current characteristics inside Residence A for the case where the wind direction is to the South. When the wind is to the South, we observed that the air flow entered from the second floor veranda opening on the East side and exited through the second floor window on the West side.

Fig. 11 shows the ventilation characteristics inside Residence A for the case where the wind direction is to the North. When the wind is to the North, we were able to confirm a state of wind inflow from both the second floor West side veranda and the second floor East side window. For both cases where the wind is to the North or the South, the inflow from the openings on the first floor is small.

CONCLUSION

In Section 1 of this study, we used an improved urban area model and CFD with 16 wind directions. We calculated the wind pressure coefficient distribution, as well as performed an analysis in relation to cross ventilation utilization. In Section 2, based on the troublesome points in the urban area model used in Section 1, we considered the effect of the surrounding topography when creating the inflow boundary conditions, and we performed the analysis with improved reproductions of the shape of, and interior ventilation for, the target structures. Compared with the analysis used in Section 1, the analysis used in Section 2 yielded more detailed calculation results. Moving forward, we plan to conduct analysis including the heat conditions, and more detailed analysis related to the internal wind speed of the target residences.

ACKNOWLEDGEMENTS

This report was partly subsidized from the 2010 fiscal year fund for research (B) of the Ministry of Education, Culture, Sports, Science, and Technology under the "Revitalization of regional culture by make the best use of historical urban clusters from an engineering approach" as represented by Hiroyuki Noguchi.

The massively parallel super computer system (HA8000 cluster system) at the University of Tokyo Information Technology Center was used to perform the calculations in Section 2.

REFERENCES

- Architecture Institute of Japan, Analysis of Fluid Values for Predicting Urban Region Wind Environments Guide Book, pp.18-22, pp.58-145, 2007.7
- Geospatial Information Authority of Japan : <http://www.gsi.go.jp/>
- Hikaru Kawamura et al.: Wind Pressure Coefficient Prediction in Traditional Architecture Clusters and Cross Ventilation Utilization Effectiveness

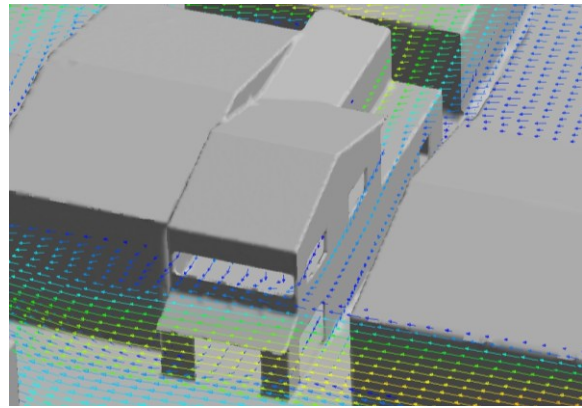


Fig.9 Ventilation of Target Residence A (Wind Direction:South)

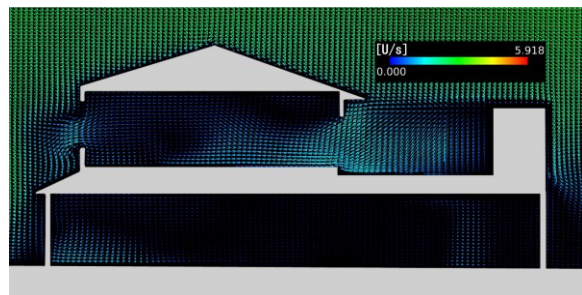


Fig.10 Ventilation in Target Residence A (Wind Direction:South)

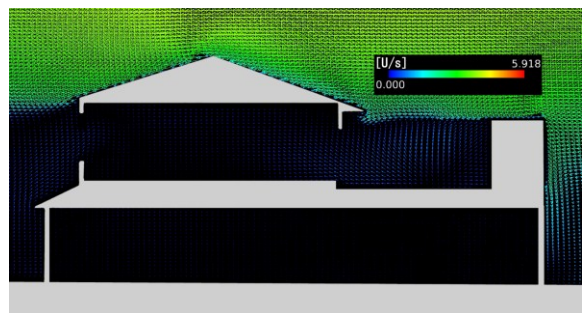


Fig.11 Ventilation in Target Residence A (Wind Direction:North)

- Verification and Air Conditioning, Sanitation Engineering Association Conference, Science Lectures Collected Papers, pp.1147-1150, 2011.9
- Japanese Meteorological Agency : <http://www.jma.go.jp/jma/index.html>
- Kokusai Kogyo Company: <http://www.kkc.co.jp/enterprise/it/laser.html>
- Yoshinori Ono et al.: Survey of the Thermal Boundary for a Refurbished Townhouse in the Kyoto Nishijin District, 2002 Architecture Institute of Japan Kanto Branch Research Report, pp. 663-666