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FEDERATION TOWER MOSCOW – DIFFERENT ROOM CLIMATES UNDER ONE ROOF

Oliver Baumann[1], and Claudius Reiser[1/2]
[1] Ebert & Baumann Consulting Engineers, Washington, D.C.
[2] Ebert-Ingenieure GmbH &Co. KG, Munich, Germany

ABSTRACT

The 'Complex Federation', also known as ‘Federation Tower’ in Moscow, Russia, a 506 m (1,660 ft) tall multi-purpose building consisting of two towers on a common podium, will soon become Europe's tallest building – at least until in 2012 the ‘Russia Tower’ with a height of 612 m (2,009 ft) will be completed. The tower caps of both towers accommodate occupancies which are most exclusive and quite challenging. At the same time the utilization has a diversity that includes wellness and recreation areas, pools, sky gardens, restaurants, VIP lounges and bars – all in one open space and under one common and completely glazed roof.

The scope of the analysis presented in this paper was to develop an HVAC concept which guarantees thermal comfort for all these occupancies and utilizations with their different requirements, in summer as well in winter. Based on in depth analyses for the building envelope (e.g. glazing, frames, tightness, solar properties, etc.) with dynamic simulation (TRNSYS 16), the climatic concept has been further analyzed and improved by evaluating and verifying the thermal comfort, i.e. temperatures, humidity and air flow, using computational fluid dynamics CFD simulation (FLUENT 6.3).

The analysis focuses on following requirements:

- absolutely no condensate shall arise on the inner surfaces of the façades;
- the temperatures in winter should be evenly distributed without any cold spots and maintained at a minimum of
  21 °C in the restaurant, bar and lounge areas
  22 °C in the Sky Club;
- the temperature in all areas should be maintained at a maximum of 24 °C in summer;
- dissemination of odors from the restaurants areas should be prevented;

Figure 1: Illustration of the Federation Tower with Tower East (right), Tower West (left) and Spire (middle).

INTRODUCTION

As part of the ‘Moscow International Business Center’ (also known as ‘Moscow City’) that comprises several newly built high-rise and super-tall buildings to form Moscow’s new 21st century city center, the Federation Tower is currently under construction. After completion in 2009, it will be the tallest building in Europe with 93 stories – at least until in 2012 the ‘Russia Tower’ with a height of 612 m will take over.

Figure 2: Moscow International Business Center construction site (Oct. 2007) with Federation Tower on the right hand side (Tower East under construction, Tower West completed).

The Federation Tower consists of two towers with a height of 365 m / 1,198 ft (Tower East) and 242 m / 794 ft (Tower West). Both towers are connected through a 506 m / 1,660 ft tall completely glazed spire accommodating panoramic elevators and antennas (see figure 1). Both towers are used for prime office and hotel spaces and accommodate highly exclusive hotel areas on the top floors, underneath imposing glazed domes. Due to the architectural challenges, the extreme climatic conditions, as well as ambitious utilization, modeling and simulation was employed in early design phases to analyze the thermal behavior of the building envelope in interaction with the HVAC concept and to achieve sufficient reliability for the system design.

This paper describes the application of different simulation tools within an integrated design process, as well as the major results and findings of the analyses for Tower East.

The tower cap of Tower East comprises four terraced top levels (level 90 - 93) with approx. 3,000 m^2 / 32,300 ft^2. A hotel lobby and reception, a restaurant and a lounge are located on the lower levels (90 and 91); the top floors (92 and 93) provide space for entertainment areas, such as dance club, additional lounges, as well as a VIP area (see pictures 3 and 4).

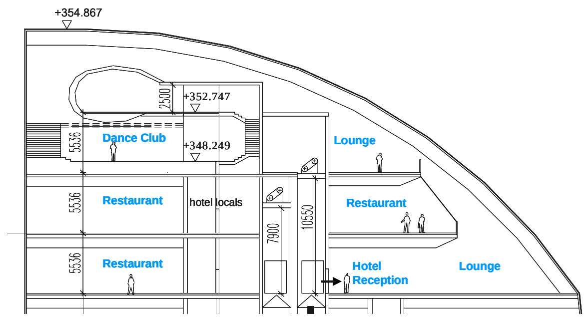

Figure 3: Section of the Tower Cap with utilization.

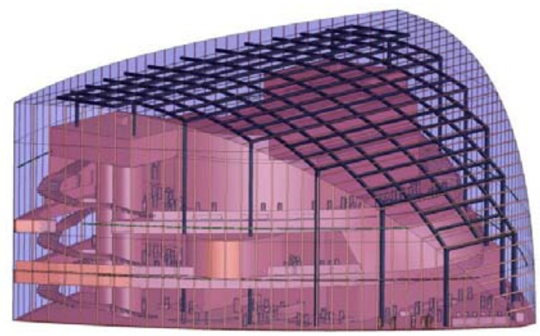

Figure 4: CFD Model of the Tower Cap.

SCOPE AND BOUNDARY CONDITIONS

Scope of this analysis was to develop a concept which guarantees thermal comfort under summer and winter conditions. Therefore, various load studies with different U-values, solar heat gain coefficients (SHGC), selective coatings, etc. for the façades are undertaken with an energy model using TRNSYS 16. Based on the decision on the results which façade concept should be followed, the climatic concept was further evaluated by a steady-state CFD simulation – applied for summer and winter case.

The climatic conditions in Moscow span over a wide range. Outdoor air temperatures – in 360 m above ground – vary from -30 °C / -22 °F in winter to +26 °C / +79 °F in summer. These extreme conditions, in combination with high wind velocities and very dynamic gusts demand specific requirements for the structure and construction, but also for the climatic concept for these luxury areas.

Limited space for technical installations and the exclusion of any visible ductwork in the open space increased the challenge to provide excellent thermal comfort in this exclusive glass dome under Moscow's sky even more.

The objective of modeling Tower Cap East was to achieve not only information on heating and cooling demand, but furthermore to answer following questions:

- Where exactly is the heating and cooling capacity needed and in what amount?
- Where are critical areas in terms of thermal comfort?
- How is the performance of the intended climatic concept and how can it be improved?

The visualization of the climatic concept with distribution of temperature, humidity, air velocity, etc. in a 3-dimensional model also helped to communicate thermodynamic processes and their impacts to the room climate to other members of the design team and the client.

THE CLIMATIC CONCEPT

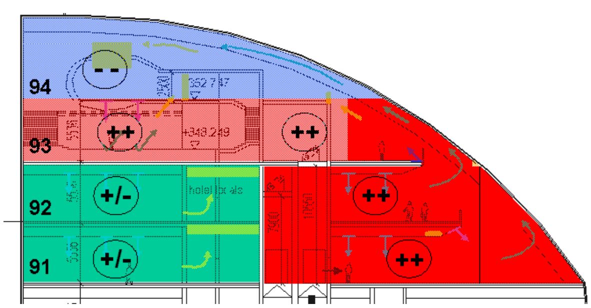

Figure 5: Pressure Zones of the Mechanical Ventilation Concept.

The climatic concept is based on a mechanical ventilation system which enables the local separation by creating different pressure zones (see Figure 5). Since there are no internal walls which would separate different occupancies, the pressure zones are essential for the separation of the open zones to minimize uncontrolled air exchanges. This means that ideally no cigarette smoke or smell of food is disseminated from one zone into another. The principle in setting up the zoning follows the air buoyancy to reduce cooling load, as the thermal layering is used. Different pressure zones are formed through different air flow rates. The exact air flow rates are listed in Table 1.

The heat is supplied by underfloor convectors along the façade perimeter and a frame heating system in the roof facade. Underfloor convectors are installed wherever possible along the external façade as well as along the balustrades. In addition, there are horizontal façade heating elements, which are mounted along the façade in the height of each floor level to prevent downdraught. The vertical façade has a height of up to 26 m / 85.3 ft. The framework of the roof is equipped with a frame heating system to compensate radiation dissymmetry and to avoid condensation issues.

Table 1 Supply and Exhaust Air Flow Rates

LEVEL	SUPPLY/EXHAUST	AIRFLOW RATE
91	Supply	14,482.0 m^3/h
	Exhaust	-11,668.8 m^3/h
92	Supply	16,068.0 m^3/h
	Exhaust	-13,600.0 m^3/h
93	Supply	13,451.0 m^3/h
	Exhaust	-12,993.7 m^3/h
94	Supply	0.0 m^3/h
	Exhaust	-5,738.6 m^3/h
BALANCE		0.0 m^3/h

The ideal air flow throughout the Tower Cap East is displayed in Figure 6. Due to varying boundary conditions, occupancies and, thus different comfort requirements, different air diffusers are used to supply the air to the space. The concept uses jet nozzle diffusers in areas with open ceiling (lounge level 91, skyclub 93), swirl diffusers in covered areas (restaurant 91 and 92) and floor diffusers along the balustrade in level 93.

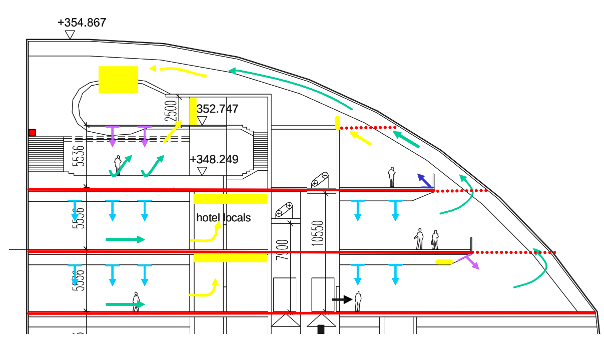

Figure 6: Ideal Air Flow of the Mechanical Ventilation Concept.

Cooling is provided by the mechanical ventilation system only, supported by fan coil units. This decission on a VAV system was reached, since the simulation showed that all the various water cooled systems which were analyzed failed to cover the cooling demand.

SIMULATION

Thermal Simulation

The general objective of the thermal simulation with the software TRNSYS 16 was to calculate the thermal behavior of the Tower Cap under dynamic external (weather and sun) and internal (persons and lighting) conditions. The results lead to a more detailed risk analysis for condensation, as well as conclusions about the temperatures in the Tower Cap during summer and winter and heating and cooling loads due to the different façade types analyzed. Based on the heating and cooling loads the climatic concept was designed to be evaluated with CFD. The goal was first to study variants with the more flexible and quicker thermal simulation. As soon as major decissions are reached, the further evaluation and desing of the final system was done with the CFD simulation. Figure 7 shows the predicted cooling load of different glass coverings. Based on these results it was decided to use the façade properties of variant 3.0 for the further CFD simulation.

Table 2 Overview Thermal Simulation Variants

VARIANT	ROOF COVER	FAÇADE COVER – OR. SOUTH
V 1.0	0 %	0 %
V 2.0	25 %	0 %
V 3.0	50 %	0 %
V 3.1	50 %	50 %
V 3.2	50 %	75 %
V 4.0	75 %	0 %
V 4.1	75 %	50 %
V 4.2	75 %	75 %

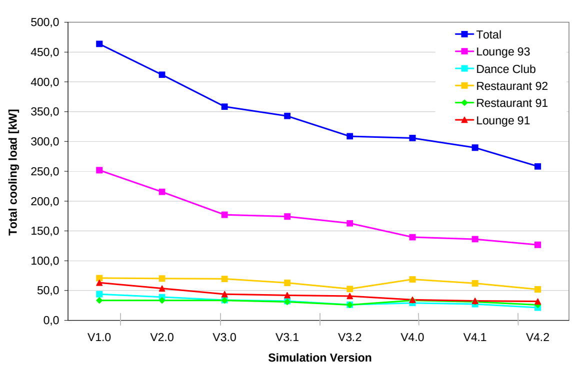

Figure 7: Cooling load in different zones depending on percentage of glass covering (dot matrix coating).

CFD Simulation

The CFD simulation has been carried out to analyze the selected technical solutions in more detail, mainly regarding the spatial distribution of room temperatures (temperature layering), humidity as well as the air distribution and air velocities within the zones. The thermal comfort was then evaluated for the actually occupied zones (comfort zones) what is not possible based on the thermal simulation, only.

The CFD simulation has been carried out as a steady state calculation for a summer and a winter case. Therefore, the inertance of building elements and materials that effect a delay and mitigation of the thermal response had to be considered within the settings of boundary conditions. The necessary parameters were provided by the thermal simulation.

A detailed 3-dimensional model of the inner structure of the Tower Cap has been created using a CAD program. Figure 4 shows the model with internal steel structure of the roof, internal walls, glazing of facade and roof, as well as staircases and balustrades. The small cylinders represent people with their accordant heat gain.

RESULTS AND DESIGN RECOMMENDATIONS

Results Winter Conditions

Thermal comfort can be achieved within the defined climatic concept. Adjustments of the system should be done for a further increase of the comfort at places close to the façade. The following heating systems were modeled in the simulation:

- convectors along the façade perimeter
- façade heating system in all frame structures at the façade and the roof
- mechanical ventilation system

The average room temperatures in the occupied zones are in a range between 21.7 °C and 22.4 °C which meets the comfort requirements. The climatic conditions with air temperatures, air velocities and inner surface temperatures of the façade can be seen in figures 8, 9 and 10. In the section of Figure 8 the supply air introduction through a jet air nozzle as well as the effect of the roof façade heating system are visible.

Figure 8: Section of the air temperature area "lounge/bar level 91".

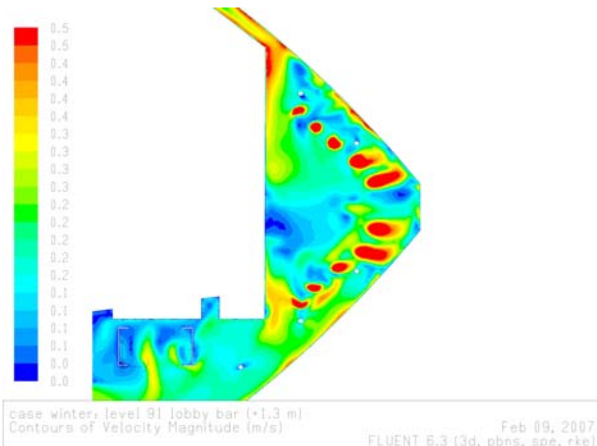

Figure 9: Air flow velocity in area "lounge/bar level 91" at a height of 1,3 m above floor.

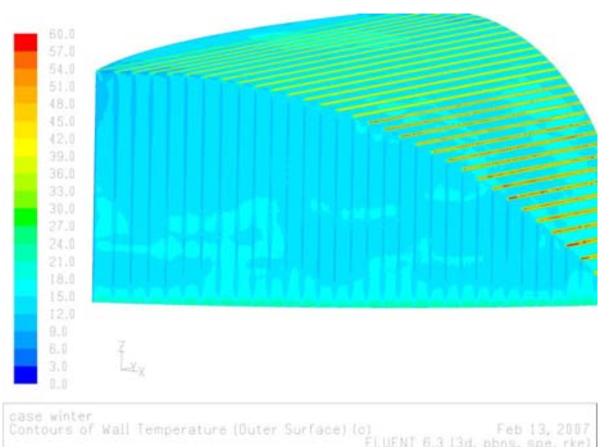

Figure 10: Room side surface temperatures.

Following summary can be given for the winter case:

- Thermal comfort can be mainly achieved by the proposed climatic concept. Slight adjustments are needed to improve local conditions.
- The convectors along the perimeter and the balustrade are needed and have sufficient heating capacity to avoid downdraught from the façade and to ensure thermal comfort in all occupied zones.
- The horizontal façade heating system in the vertical facades has not enough capacity to avoid condensate in all areas and can not guarantee sufficient thermal comfort close to the façade. Therefore, additional heating elements in the vertical frame structures were recommended.
- The façade heating system of the roof (61 W/m² roof area) prevents condensate as well as discomfort due to cold surface temperatures.
- Humidity control is recommended for all central AHU's to maintain adequate supply air conditions for minimizing the risk of condensation.

Results Summer Conditions

The designed climatic concept ensures the thermal comfort in nearly all areas. Room temperatures are predominantly within the specified range, although there are areas where the actual temperatures are above the maximum values. Level 91 to 92 show uncritical temperatures; the mechanical ventilation concept provides comfortable conditions. Slightly higher temperatures occur in the bar on level 91, which is more exposed to solar radiation than other areas.

The most critical area in summer is the terrace on level 93 (see figure 12). The simulation results show that due to the relative low room height, the thermal layering is not strongly developed. This fact as well as the high heat flux through solar gains leads to higher room temperatures.

An increase of the air flow rate by 100% along the terrace edge and additional air inlets evenly distributed as well as an increase of the roof coverage to 75% will keep the room temperature in the required range. A glazing coverage by 50 % only, as it was determined by the thermal simulation and initially set up in the CFD simulation does not reduce the solar radiation sufficiently, especially on the terrace areas (see figure 13).

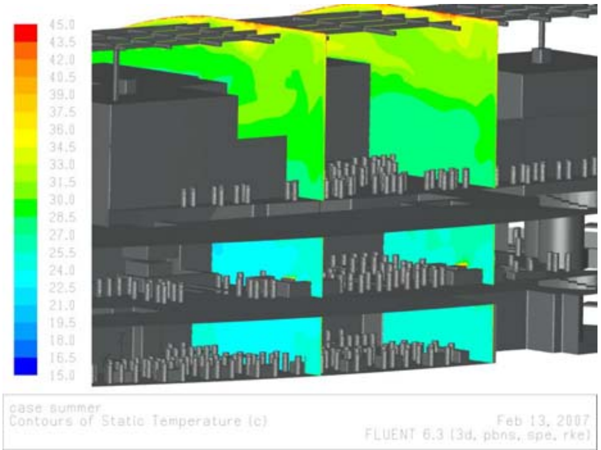

Figure 11: Overview – air temperature in the back of Tower Cap A, vertical section.

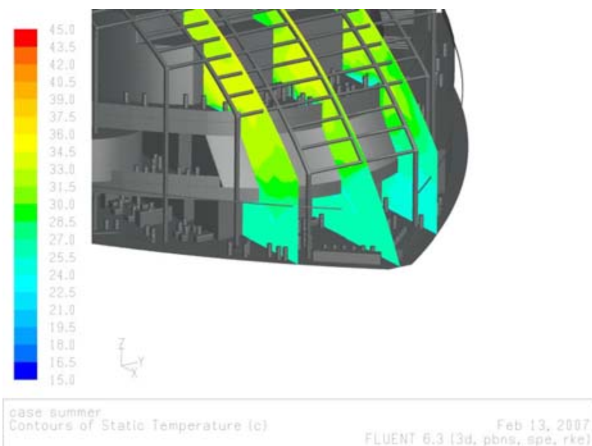

Figure 12: Air temperature along balustrade in level 93.

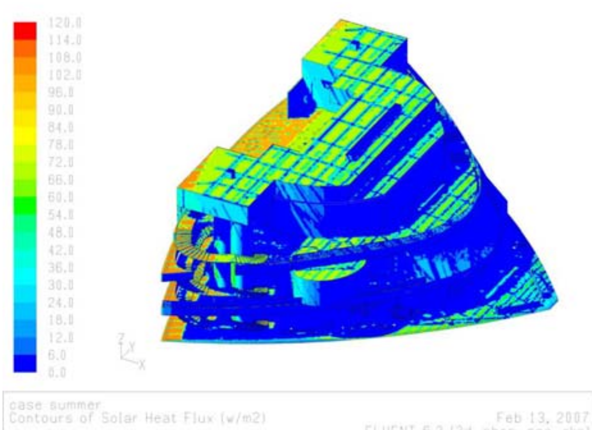

Figure 13: Solar heat flux distribution on floors and walls.

Following summary can be given for the summer case:

- Thermal comfort can be achieved in almost all areas by the proposed climatic concept. Modifications of the façade coverage as well as the climatic concept are required in order to reduce the room temperature on level 93 along terrace edge.
- A closed restaurant area on level 92 along the terrace edge is necessary to reduce the significant influence on the comfort from the Bar on level 91.
- Room temperatures can get higher than previously defined – but are still acceptable.
- The balustrades need to be closed at the floor along the terrace edge to maintain appropriate comfort conditions on level 92 and 93.
- It is recommended to provide additional cooling capacity by increasing the air flow rates.

CONCLUSIONS

The execution of dynamic calculations and CFD simulation in particular allowed modeling the challenging situation of Tower Cap A – architectural and technical – and to analyze and optimize design solutions in detail. The CFD model included architectural and structural details, such as columns, beams, frames, stairs, etc. as well as 27 jet nozzles, 167 diffusers, façade heating system, and convector heating.

The anticipated climatic concept for heating, cooling and ventilation could be optimized in regard to comfort, technical installation and, thus costs. The analysis of the simulation results convinced the design team and client in the reliability of the developed and further optimized technical solutions. As a result, the required overall cooling capacity could be reduced by 50 %. This was possible as the thermal layering was used and only the actual occupied space was conditioned. The costs for the simulation study were only a fraction of the costs for technical installations which have been reduced or even avoided.

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