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Concerns: Advances in combined building thermal simulations and prediction of air-flows with CFD

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***Advances in combined building thermal simulations and prediction of air-flow with CFD***

Evermore buildings with large glazed spaces like atria are being designed and built. Often these atria are complex shaped and are laid out with a sophisticated HVAC concept. High demands on interior climate are posed throughout the whole year. Due to their design the large portions of glass might cause the atria to overheat during a significant part of the year and, on the other hand, during winter cold downdraughts might occur.

*Figure 1: atrium of new built WTC Amsterdam*

In order to compute and analyse these effects, Peutz BV in the Netherlands, have developed a special software program that makes it possible to perform dynamical thermal building simulations combined with an integrated air-flow computation with Computational Fluid Dynamics (CFD).
The new program has been based upon the commercial available CFD package Phoenics 3.5 by Cham Ltd of London.

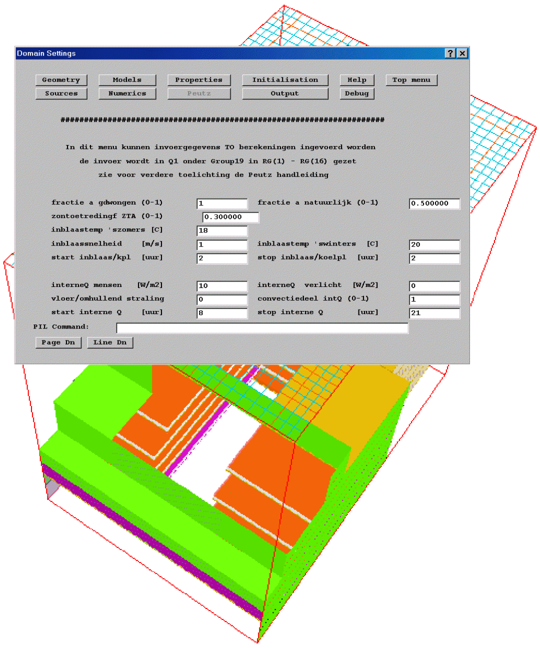
With this program, temperatures as well as air-flows inside offices, atria and coupled spaces can be predicted. Further advantage to TRNSYS, TAS, BFEP and comparable software for instance is the detailed solution of vertical temperature gradients.
Compared with a traditional CFD computation the ease of automatic control of varying solar irradiation, internal and external shading by buildings and constructions, HVAC control and varying internal heat gains is a striking feature. Therefore, one is no longer obliged to perform the tedious repetitive procedure of computing and entering such matters manually at every time step.
When performing a complex study this can save a significant amount of time, often up to several working-days!

To that end, Phoenics has been extended with several subroutines of a traditional Dutch building thermal simulation program, BFEP. Furthermore, a new subroutine has been added that automatically exchanges the geometrical data from the CFD model to these subroutines and vice versa.

## APPROACH OF A SIMULATION

The computational model, devised in the pre-processor of Phoenics, has a dynamical, i.e. transient, nature, so as to properly deal with floor- and wall temperatures as a function of accumulation of heat (taking into account the inert masses).
Prior to the simulations a model of the entire building or atrium at hand can be set up, employing the graphical user interface of Phoenics, which, to that end, has been extended with several dedicated input screens for input data concerning HVAC control, g-values and internal heat gains, see figure 2. Results can be visualised with its post-processor.

*Figure 2: PHOENICS VR model of atrium with dedicated input screen*




As with traditional building thermal simulation software, a climate-data-file of a reference year is read by the model at each time step. If so wished, the building performance during an entire year can be simulated.

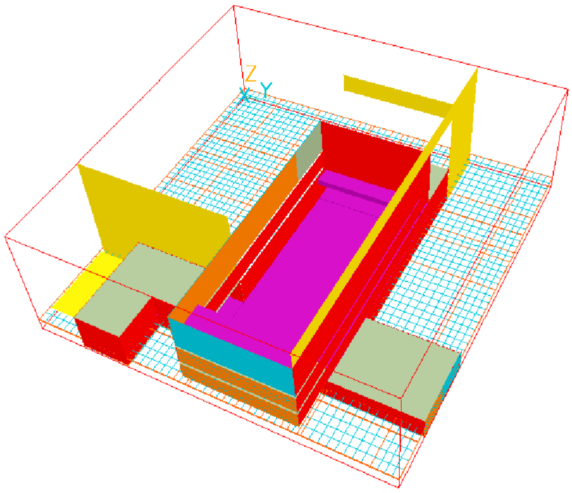
## ON THE TECHNICS OF THE NEW SIMULATION PROGRAM

The new simulation program employs an advanced ‘surface-to-surface radiation’ model, a model which has been altered by Peutz BV in such a way that it automatically computes view-factors, surface temperatures and radiation exchanges in the building or atrium.

Moreover, in the matter of internal and external shading it accounts for all opaque material surfaces. It discerns windows, diffuse as well as direct solar radiation and sun-blinds, see figure 3. For that purpose the ray-tracing method is applied.

In figure 3, the grey and yellow plates represent objects causing internal and external shading (adjacent wings of the building at hand) respectively, being accounted for by the same subroutines, automatically.

*Figure 3: PHOENICS VR model of atrium 'De Weerde' Eindhoven, The Netherlands*



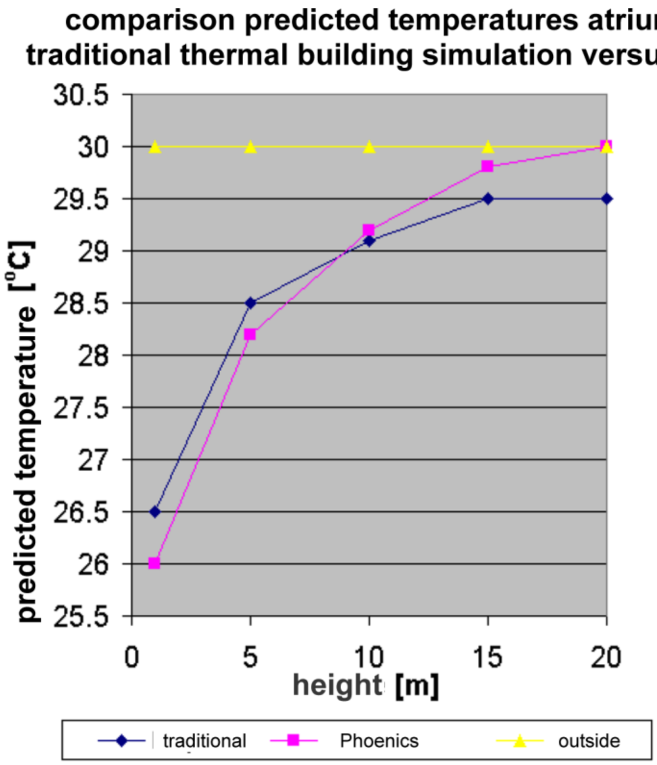
Users of a CFD program usually have it compute heat transfer coefficients (between on the one side air and on the other side floors and walls) by means of the so-called 'standard wall functions' offered by the program. However, in building physical applications this is probable to yield irrealistic, often to low, amounts of heat transfer. Therefore, Phoenics has been altered by Peutz BV in such a manner that it uses empirical formulas for the heat transfer yielded by differences in temperature and forced convection. At each time step, we have the program update all air-solid interfaces. Computations appear to be more reliable, stable and to proceed faster in this manner.

**ON VALIDATING THE NEW SIMULATION PROGRAM**

With the above-mentioned traditional thermal building simulation package, BFEP, we have undertaken a series of computations for comparison purposes. The intention is to validate the present CFD program on the basis of studies in the past, for instance the atrium of the newly built WTC Amsterdam, see figure 1.

The chart in the sequel shows how the temperatures computed in either way compare for a high atrium with a tall glazed facade and roof, with supply of chilled air at floor level.

*Figure 4 chart showing validation atrium on the basis of BFEP*




Differences appear to be small, ½ K viz. However, a striking feature is the larger vertical temperature gradient predicted by the CFD model. This occurs as a result of imperfect mixing of cold and hot air, something traditional programs often assume. Hot air shows a tendency towards streaming directly upwards in the shape of a plume, without mixing too much, creating a layer under the ceiling. This may bring about overheating on foot-bridges or galeries at the highest floors.

**STUDIES UNDERTAKEN BY PEUTZ BV**

Recently several studies have been undertaken for Dutch and German commissioners employing the present CFD program. In the sequel four of them are discussed.

***New Sittard headquarters of Saudi Basic Industries Corp (Sabic)***

Arcadis commissioned Peutz to study the indoor climate during summer in the Sittard headquarters of Sabic, currently under construction.

The building consists of a vast open space that comprises six office floors as well as a central void. The building has a glazed facade with solar glazing combined with interior sun-blinds as well as a glazed atrium roof.

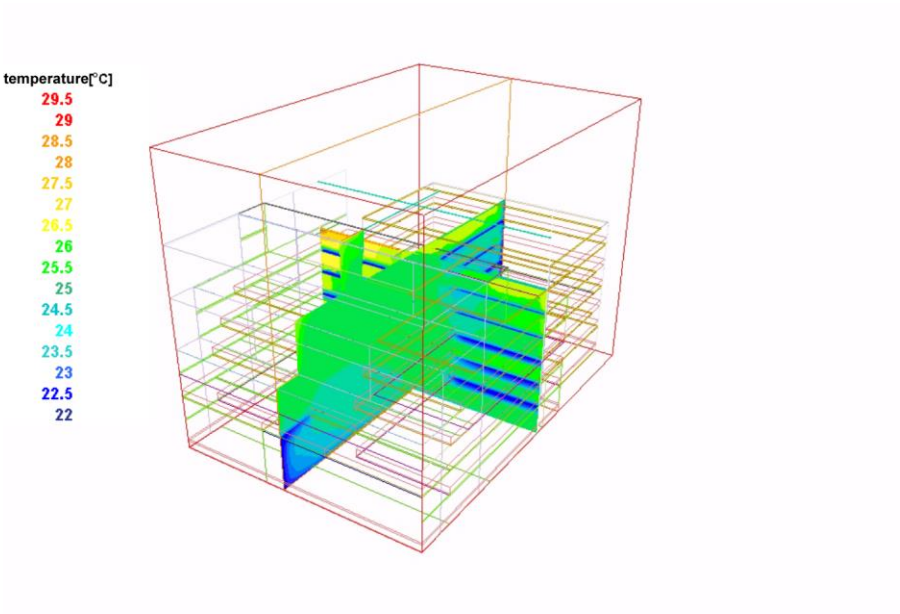
It is of paramount importance to prevent large-scale air-movements throughout the office floors and the central void. Furthermore, the vertical temperature gradient should be limited, to prevent the highest floors from overheating.

Arcadis have designed several HVAC-concepts. Purpose of the study was to chose the optimum concept from the proposals of Arcadis and then to optimise the chosen one further. Moreover, it should be examined whether the starting points in the preliminary design concerning the facades and glazed roof combined with the HVAC concept chosen could meet the demands posed to the interior climate.

Based upon preliminary CFD computations mechanical ventilation by means of ceiling diffusers and chilled ceilings with proportionally cooling control. Air exhaust takes place at the top of the central void.

As appears from figure 5 the temperature distribution is fairly uniform. Computed temperatures amount to 25 ºC at all levels, except the fifth. At levels 5 and 6 the computed situation is slightly amenable to betterment, because of the glazed atrium roof with its interior sunblinds as well as some infiltration air that moves upwards through the central void and enters the upper floors.

*Figure 5: predicted temperature distribution atrium Sabic under construction*




It is deemed necessary to increase the cooling capacity at the upper floors and to close the boardrooms at the sixth level. Furthermore, along the north-west facade the cooling capacity has been slightly increased.

At the ‘Plaza’ on the first level the ventilation quantity has been slightly decreased in order to reduce the risk of cold downdraught towards the entrance area.

***Atria of new headquarters developed for CC-Bank Mönchengladbach***
Currently a new headquarters is being developed for the CC-Bank in Mönchengladbach. Peutz Consult GmbH have performed a series of computations of the internal thermal climate in two atria. Special feature of the atria is the fact they are interconnected by a wide and high corridor.
Among other things, purpose of the computations was to predict possible draught phenomena as well as to minimise them.

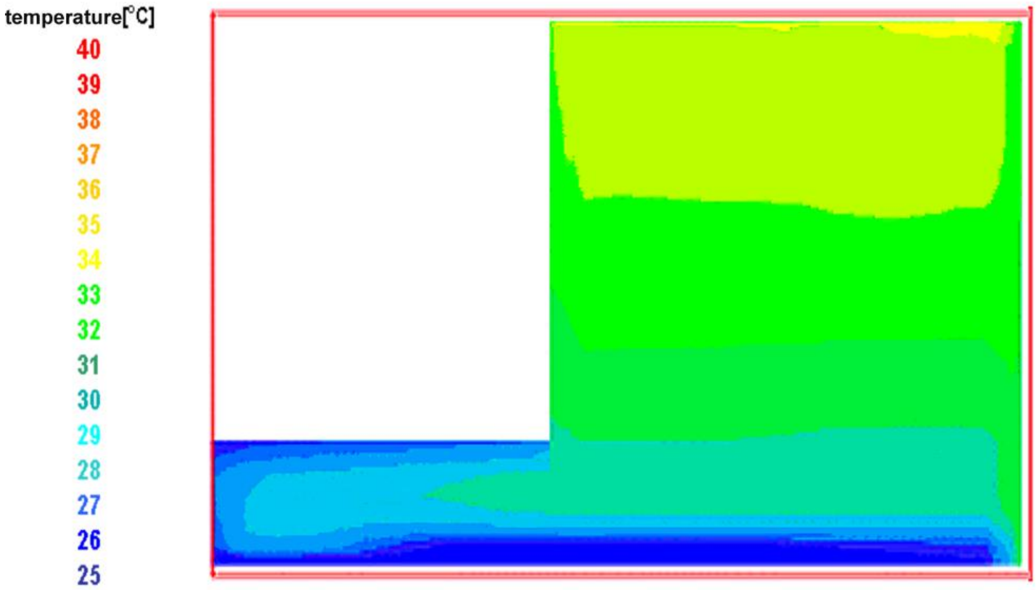
Different computations for both the summer and winter situation have been performed on different qualities of facade lay-outs and solar shading devices.
Additionally, the effect of a number of chilled ceilings underneath the galeries around the atria has been subject of research.

The atria are not meant to be occupied by persons, but are devised so as to connect the various office buildings within the development. Only the restaurant in the southern atrium is an occupied area.
Natural ventilation by means of glazed louvers in facades and roof is provided in the design. However, internal temperature may sometimes exceed the outer temperature caused by solar irradiation and internal heat-gains. By means of a chilled floor as well as chilled ceilings combined with the added effect of accumulation of heat by the natural stone floor and walls the internal temperature can maintained within properly set limits.
Purpose is the limit the internal temperature so as not to exceed the outer temperature. In the restaurant, the temperature has to be substantially lower.

During winter the atria are partially heated, i.e. with an outer temperature of –10 degrees centigrade the atria should maintain a temperature of at least 18 degrees centigrade. Actually a so-called ‘half-climate’ is pursued. Apart from that, cold downdraughts from the glazed facades have to be minimised to a large extent. Besides a heated floor, with a more dense grid of tubes along the facades, heated ribbed tubes are to be placed at several heights along the glazed facades.

In the figure in the sequel the predicted vertical temperature gradient in the southern atrium is shown. It corresponds to a situation in the afternoon on a hot and sunny summer day. As can be expected, the vertical temperature gradient has a considerable magnitude. At the highest level, where a foot bridge is planned, the predicted temperature may exceed the outer temperature if no additional measures are taken.

*Figure 6: temperature gradient atrium CC-Bank without additional measures*

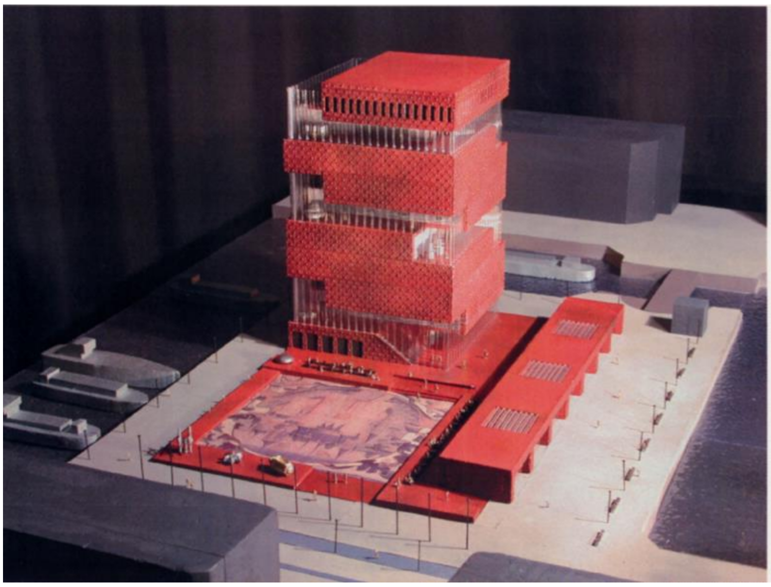



Peutz have therefore advised to provide the southern facade with solar glazing as well as exterior sun-blinds. At the location of the roofs, large construction beams are present, which are expected to block a large portion of the solar irradiation that, on its turn, will disappear through the ventilation louvers in the roof.
In the surrounding occupied office areas, only light screens are needed in this case.

According to the computations, during winter a sufficient reduction of the cold down-draughts is feasible by means of the heated ribbed tubes. Even in the restaurant, an occupied area after all, the predicted thermal comfort now appears to be satisfactory.

***Design glazed gallery Antwerp 'Museum Aan de Stroom'***
In Antwerp the 'Museum Aan de Stroom' is being designed by Neutelings Riedijk Architecten. For these Dutch architects a study has been undertaken so as to predict and optimise the thermal climate in the nine level glazed gallery surrounding the museum in the shape of a helix, see figure 7.

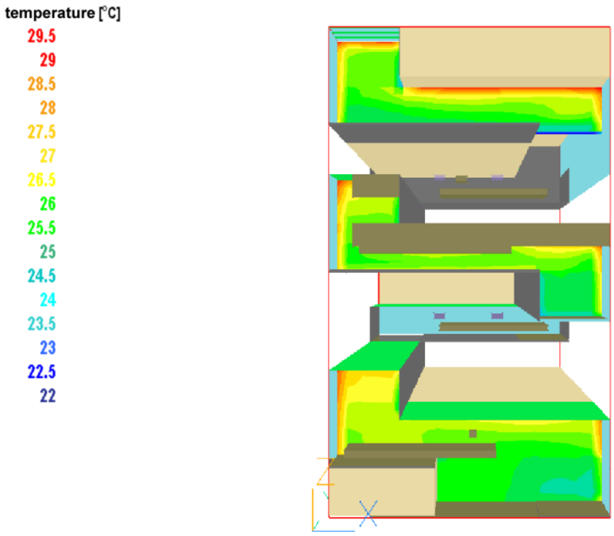
*Figure 7: Design of Antwerp 'Museum Aan de Stroom'*



In contradiction to the exhibition spaces where one poses severe demands on the climate, in the gallery one aims for a 'half-climate'. Central question is how a satisfactory thermal climate can be acquired despite application of single pane glazing in the facades of the gallery, for single pane glazing has constructive (possibility of bending) and aesthetic advantages (less reflections, more transparant) and is less expensive than double pane glazing. In the sequel we discuss both summer and winter climate.

Summer-ventilation of the gallery takes place by exhausting chilled spill air from the exhibition spaces. Furthermore the natural stone floors are chilled by means of a water circuit. Accumulated solar heat is removed by means of this water circuit and by night-ventilation, as inert floors and walls need time to cool down.
Figure 8 presents predicted temperatures in a vertical cross-section through the museum with half-transparent and highly reflective automatic interior sun-screens.

*Figure 8: predicted peak temperatures in gallery Antwerp Museum Aan de Stroom*




During winter a ‘half-climate’ is also achieved, with mean temperatures of approximately 15 ºC. As a matter of fact, inner surface temperature of the glazing is mainly determined by the outside temperature, often further reduced by nocturnal radiation from clear winter sky. Therefore, floor heating by means of the water circuit is of paramount importance in order to reduce the risk of surface condensation on the glazing. Additionally, sufficient supply of pre-heated dry air is necessary, i.e. at least twofold ventilation at an outside temperature of –8 ºC.
Exhibition spaces are maintained at under-pressure so as not to let humid air enter the gallery.

Thus, most important features of this gallery are the heating and cooling by means of the water circuit in the natural stone floor, the under-pressure in the exhibition spaces and the half-transparent highly reflective automatic sun-screens in the gallery.

***Biosciences Centre University of Liverpool***
For the University of Liverpool the ten storey high rise of the faculty of Biosciences has been refurbished. BDP have commissioned Peutz BV to undertake wind tunnel measurements and CFD computations on behalf of the building, consisting of an atrium between the existing and the new high rise as well as adjacent open research, office and teaching floors.

The building has been provided with natural ventilation with fresh outside air being supplied through operable windows in the facades and exhausted through automatically controlled louvers in the roof.
The atrium rises several meters above roof level in order to augment the thermal stack-effect and to avoid stagnant hot air conditions at the upper laboratory floors.

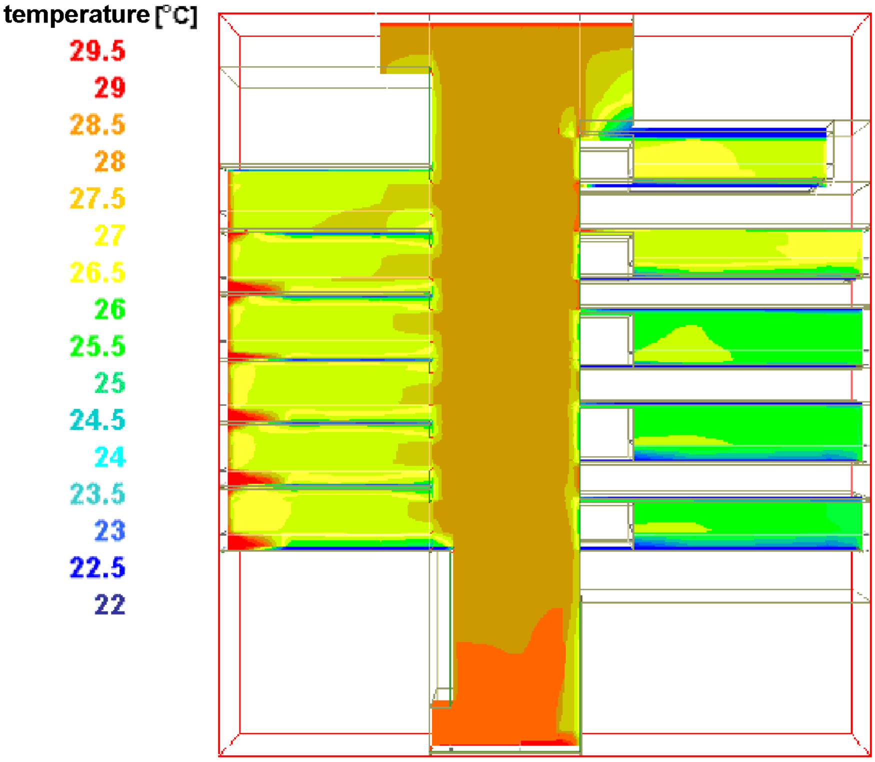
At the occupied floors the building takes advantage of thermally open ceilings, thus making good use of the inert mass of the concrete construction. Night-ventilation will further contribute to a reduction of the peak-temperatures, due to cooling the concrete construction.
Moreover, the southern facade has been provided with fixed wooden outside sun-blinds.

Firstly we performed a wind tunnel measurement in order to gain insight into the wind conditions at the various windows and louvers.

*Figure 9: wind tunnel model of Biosciences Centre Liverpool*

Based upon the measured wind pressures the performance of natural ventilation of this building during a hot summer week, at several wind speeds and directions has been simulated, see figure 10 for an example.

*Figure 10: predicted peak temperatures Biosciences Centre University of Liverpool*




The figure shows that, due to the measures mentioned in the above, the temperature can be limited to just below the outside temperature, assuming the internal heat gains are maintained below approximately 35 W/m$^2$.
In order to reduce the sensitivity of the ventilation to wind effects we have also proposed to automatically close the windward louvers in the top of the atrium.

A surprising fact is the atrium itself should not be laid-out with operable louvers or windows in order to avoid an unfavourable 'short-circuit' in the ventilation system.

Finally, during winter the atrium floor is heated and special ribbed heat coils are put at several heights along the glazed facades of the atrium in order to reduce cold down-draughts which might otherwise have impaired thermal comfort in the atrium.

***Summary and concluding remarks***

Peutz BV in the Netherlands, have developed a special software program based upon the commercial CFD package Phoenics 3.5 so as to be able to conduct dynamical thermal building simulations combined with an integrated air-flow computation.

With the dedicated program, temperatures as well as air-flows in offices, atria and coupled spaces can be predicted. Advantage to traditional thermal building simulation software is for instance the detailed solution of vertical temperature gradients.
Compared to a traditional CFD computation, automatic control of varying solar irradiation, internal and external shading by buildings and constructions, HVAC control and varying internal heat gains, is very convenient.

Most striking feature of the projects presented here is the optimisation of HVAC and reduction of solar heat gains in the discussed atria.
Properly speaking, solar glazing or sun-blinds here and there, a local chilled ceiling or floor as well as shifting of air supply quantities, often will do.
Nevertheless, considerable improvement of thermal comfort: i.e. more uniform temperature distribution, less draught, no overheating of the upper storeys and foot-bridges, can be obtained.

Furthermore, this program significantly extents the range of spaces like atria as well as the range of HVAC-concepts that can be properly modelled and simulated.

Due to this sort of computations a substantial gain in quality and confidence can be obtained on behalf of the building services consultant and building commissioner, at reasonable costs.

And, last but not least, automation and quality control result in complete thermal building simulations with CFD at reasonable prices.

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