Academic year 2020 - 2021 #1 | December

MOLLIER

Study Association
Building Physics and Services

INSIDE INFORMATION

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Modified mixture design of self-compacting concrete

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PDEng project: Intelligent solar shading systems

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THE ABSENCE OF SHADING CONTROL CASTS A SHADOW OVER WORKING AT HOME...

Foreword

Laurens Castenmiller

Dear reader,

It is with great enthusiasm that I can present to you the first edition of the INSide Information for the academic year 2020 – 2021.

The INSide Information falls on the doorstep twice a year, and sharing knowledge is the key goal of this magazine. In each edition, different topics like, sustainability, lighting, energy, and systems are presented from the different research chairs in the Unit Building Physics and Services. I am honored to be a chairman of Mollier, the study association of the Unit. You can find a more comprehensive introduction to myself and the rest of the 25th board in the "Introduction to the Board" section, along with other interesting research in the unit and messages from our partners.

In the recurring topic "Ice-Breaker", Sil Schaars will introduce herself as one of our new members. The graduation project of Daria Zendri is presented, who researched the technical and environmental benefits of the modified mixture of self-compacting concrete. Another article is written about a digital test environment for advanced building skins by Martijn van Ballegooijen, on the topic of digital environments. Jill Vervoort has written about her life after BPS and her experiences of being an employee at De Groene Grachten and two articles by our partners Valstar Simonis and Actiflow are presented. In the column BPS Basics, the importance of circularity is explained by Hajo Schilperoort. Finally, I will kick off a new topic: as a graduated bachelor student, I will share my experiences from the bachelor end project.

Together with the board, we continue to organize activities for our members and alumni; if not offline, then online. This academic year is special because Mollier celebrates its 25th anniversary! We would like to see all of you at our lustrum activities, which you can find on the Lustrum page of the Mollier website. The lustrum committee is working hard to be able to organize all activities where possible in real life, in accordance with the guidelines of the RIVM. Furthermore, we have some traditional fun activities coming up, such as the beer tasting and the cocktail party. If you're enthusiastic about organizing such an activity, we are looking for you! Feel free to contact the 25th board!

For now, stay safe and a lot of fun reading all the impressive articles to catch up with Mollier!

Laurens Castenmiller

Chairman, 25th board of s.v.b.p.s. Mollier

INSide Committee
Laurens Castenmiller, Meghana Kulhalli, Nora Kuiper

COLOPHON

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This INSide


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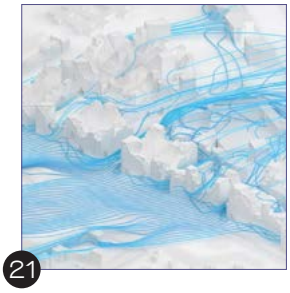
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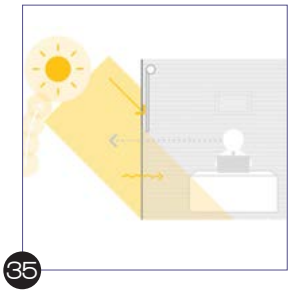
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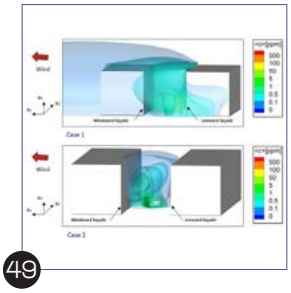
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Introduction to the 25th Board of Mollier

LAURENS CASTENMILLER, CHAIRMAN

Hi all, my name is Laurens, and 24 years old. I'm born in Amersfoort and raised in Nijverdal, which is near Almelo and in the east of the Netherlands. I had an accident with the bike (see next paragraph) and in the hospital, I had enough time to think about the discipline I wanted to focus on, which is BPS. two years ago I joined Mollier while I was still a bachelor student. I'm diligent to learn new things, so I decided to join the board of Mollier last summer. This academic year I will be the chairman of the 25th board of Mollier, and at these pages, you get to know the board.

Besides being a board member, I'm also a member of the student cycling association Squadra Veloce. Cycling clears my head and provides extra energy that I can put into my study afterward. I have cycled the elfstedentocht (235 km) twice, but unfortunately, COVID-19 did cancel the event this year, so there is no third time yet. A rather serious accident with the bike, 6.5 years ago, brought me into a coma for one week but did not take away the love for cycling (*"pain is temporary quitting lasts forever"*). I recovered and am open to speak about it, so if you have questions about it, feel free to ask them. And if you want to cycle together with me, feel free to ask me!

Apart from cycling, I appreciate good music and listen to many kinds of music, especially country music and somewhat older music. I visit many concerts and like to visit festivals with my friends. As a part time job, you could find me behind the bar at festivals all over the country. With this job, I'm occasionally able to join the festival ground, enjoy the music behind the bar, and earn money at the same time.

I spend most of my salary on soccer. Even though I study in Eindhoven, and am raised in Nijverdal, I support Ajax. I have a season ticket for all home matches of Ajax. After a disappointing result, of an important match, I'm not approachable for about one hour. The train journey from Amsterdam to Eindhoven takes more than an hour, which is an advantage because then I have been able to put soccer into perspective.

I hope this year will be an awesome academic year. If you have difficulties or questions, you can contact me on floor 5 or feel free to send a mail to chairman@mollier.nl.

JESPER PRIESTER, COMMISSIONER OF ACTIVITIES AND VICE-CHAIRMAN

Hello reader, I'm Jesper Priester (as you probably already saw in the header above) and am 24 years old. The small village of Kats in the province of Zeeland is where I grew up. If you like the countryside and love to have your seaside and beaches nearby you could call it nearly ideal.

After I finished my havo I wanted to do a technical study, looked for chemistry and civil engineering but eventually preferred building engineering. This I did at what is colloquially just known as 'HZ' and is an abbreviation of Hogeschool Zeeland. Within this study, I gained more and more interest in building physics. Therefore I focussed on this as much as possible within the program and mostly the internships. This was not enough to my liking and was determined to do a masters.

While doing my graduation internship I was already unintendedly part of my first Mollier activity; later many more would come. Back then Mollier visited the laboratories of Peutz while I was there for my internship. I enjoyed it a lot and so the first contacts with Eindhoven were made. Together with a lack of interest in the studies in Delft, BPS it was. Even though I sometimes strongly think not, I still am very happy with that choice.

Fast forward time roughly two years and now I'm responsible for the activities within the 25th board. This is combined with the role of vice-chairman. The whole COVID-situation has for sure its impact on the activities. However, they are and certainly will keep coming. I hope we can see each other at one of the activities!

Dearest reader,

You might remember us from last year! In June 2019, we became the candidate board of Mollier, the five of us having different backgrounds regarding origin and previous studies. In September 2019, we were officially constituted as the 24th board of Mollier and together, we had a blast leading Mollier.

We organized all sorts of educational-, career-related- and fun activities for our members and alumni. We organized our traditional events, such as the monthly lunch lectures and the start activity, as well as some new events. We introduced the first ever comfort kitchen, with the help of Meghana and Daria, a well organized pubquiz by the ever enthusiastic pubquiz-committee and a workout activity, hosted by Cristiane!

Of course, we had some ups and downs during our board year, with the Covid-19 pandemic as our biggest challenge. We are very proud that we managed to move activities online, in order to still connect with the members and the companies. We introduced online "dinner lectures" with our partners to replace the lunch lectures that could not take place, and we moved the beer tasting and the cocktail party online.

At the end of the year, when we were allowed to organize some offline activities again, we organized an active members barbecue to thank everyone who joined committees in the past year, and we organized a very successful end activity at the end of the summer!

We are looking back at a successful year, as the 24th Board, and are excited to look forward as well, as the 25th Board of s.v.b.p.s. Mollier! Together with Laurens as the new chairman and Jesper as our commissioner of activities, we are in the board of Mollier for a little while longer. Feel free to contact us for any questions regarding the association and the members (contact Júlia, our super secretary); the finances of the association (contact our treasure(r) Sietse); the educational program (contact our toppers Eugene and Bas); or career-related questions (contact Bas and Nora, well-willing to connect you to any company that you are interested in).

We hope to see you soon at one of our activities this year!

Much love,
Júlia, Sietse, Eugene, Bas and Nora

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Mollier Activity Calendar

ACTIVE MEMBER BARBECUE

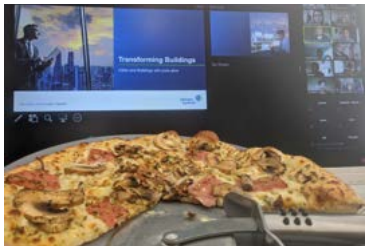
On the 4th of July, the active member barbecue took place to thank everyone for the commitment and effort that everyone put into organizing the past activities last academic year. The barbecue was turned on, and while enjoying a beer or a glass of wine the evening turned to be a pleasant evening. To express the gratitude to all active members, everyone received a beautiful plant, specially selected for the particular person. Also a specific message was attached to the plants as a memory for the active attitude last year.

END ACTIVITY

In the last weekend of August, we could finally organize an offline End Activity. As our start- and end activities are organized as a fun bonding weekend together with other members of the association, we really valued organizing this activity. This year, instead of going far from home, we stayed near Eindhoven. The weekend started with a scavenger hunt by bike, leading to the viewpoint over Groot- en Kleinmeer, and to a pub in Vessem where we treated our participants on a well deserved beer. After the short break, it was time to continue to Oost-, West- en Middelbeers, where the committee had rented a large group accommodation. The house for almost 50 persons offered enough space to keep 1,5m distance for our 23 participants. The evening was kicked off with a nice dinner, prepared by the committee and their recruits, Meghana, Marc and Jesper. After dinner, it was time to play an alternated version of 30 seconds, where groups of four played against each other. The evening ended with some more games, and catching up after the summer break. The next day, we started with an excursion to a sheep herding farm, where we got an elaborate instruction on how to herd sheep, with and without a well-trained dog by your side. For the afternoon, the committee prepared a so-called "zeskamp", with corona-proof battles between the teams. This was a large success, and everyone could relax and regain strength with a luxurious barbecue. The finale was played in the dusk, where the teams battled each other in a game of outdoor laser game. After the laser game, we had some relaxing time, where some people exhaustedly went to bed early, while others continued to chill until the wee hours. The next day, we cycled home in unfortunately horrendous weather. We planned a pit stop at a restaurant along the way home, where the overall winner of the weekend, Maud, was crowned with a special beer package. We'd like to thank the committee, Sietse, Júlia, Bas and Nora for organizing this amazing weekend for us!

GMM #4 - CONSTITUTION

On Tuesday, the 22nd of September, we organized the last GMM of the 24th board, and the first GMM of the 25th board. The constitution of the 25th board took place, with the members of the 25th board unanimously chosen.
After the GMM, the board celebrated with a beer at the CSPO XL, organized by the 35th board of CHEOPS, and afterwards with a dinner at the Zwarte Doos. We welcomed our members to join us at 19:00 to have a toast on the new board and the new academic year. Due to corona, this unofficial constitution drink took place in a different way than we are used to, but we are very excited to hopefully organize a real constitution drink somewhere in the first half year of 2021!

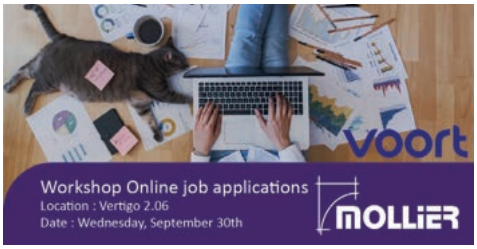


DINNER LECTURE #1, #2 AND #3

Since the worldwide outbreak of Covid-19, we have been challenged to move some traditional activities online. At the end of last year, we successfully moved our lunch lectures online. Even though the lunch lectures were allowed on campus for a short while, we decided to keep them online, as an online audience was expected to be bigger than an offline audience. Johnson Control kicked off the series of online lectures in September with an interesting presentation on their OpenBlue platform, developed to evaluate the building performance. Van Hout and Klictix presented together in October, both focusing on the indoor climate. As the presentation by Van Hout was specifically about the indoor climate in schools, we had no other than Wim Zeiler as our special guest. These two first dinner lectures really fitted well in quartile 1, as it connected to the course Intelligent Buildings. The first lecture of quartile 2 took place in November: we got an introduction by Lada Hensen and Cristina Papachristou on the PDEng program "Smart Buildings and Cities", and an interactive presentation by ZRi, on the "Academie Tien"-building in Utrecht. We are really proud that we managed to continue with these career related lectures, despite the pandemic and are glad that so many people are enjoying them.

VOORT WORKSHOP, ONLINE JOB APPLICATION

On the 30th of September, Voort invited us for a training in (online) job applications. The workshop was given by Sam and Carlyn from Voort. They treated us with some important tips and tricks, and do's and don't regarding the online job application process: how to prepare (make sure to ask questions!), how to dress (even if it is online) and how to act (have an active attitude). Overall, the training was very helpful, and we'd like to thank Voort, and especially Sam and Carlyn, for organizing it with us!

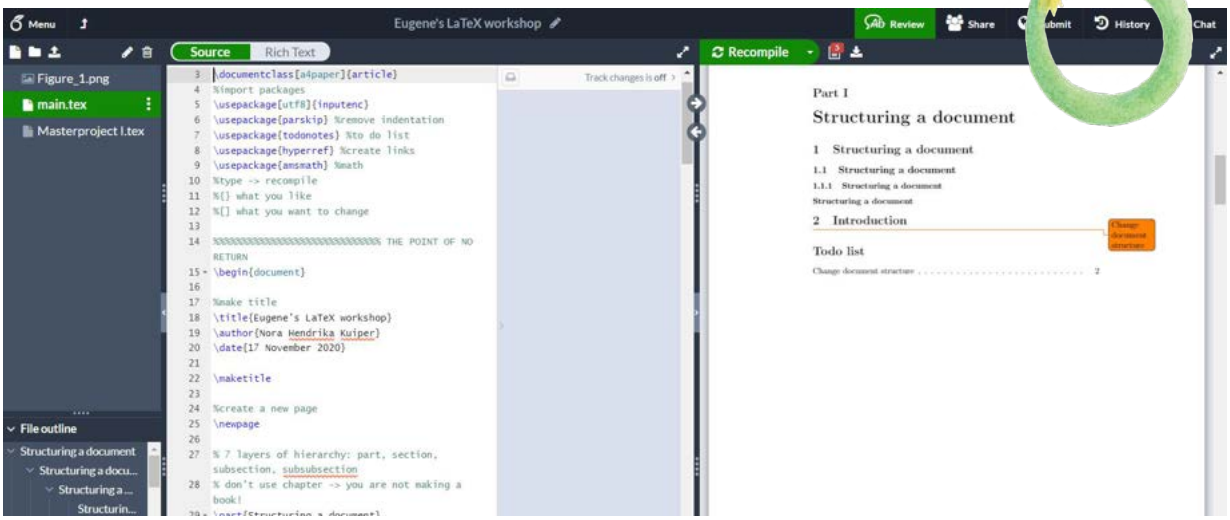


PUMPKIN CARVING

October 31st is Halloween, and Richard couldn't neglect this special day. He didn't want to shout trick and treat at the doors and he also had no desire to dress up in order to frighten people. Richard wanted to organize an activity and carve a pumpkin together with the members of Mollier, and create some pleasant, beautiful or frightening creations. A pumpkin was brought by everyone that participate in this activity. After a while of careful thought, the great ideas were drawn on the pumpkin, and the carving began. With a sharp knife the creative ideas, drawn on the pumpkin, could be cut out of the pumpkin. This went smoothly and everyone remained unharmed, even the member who dared to sit, in his orange sweater, next to someone who was cutting the orange pumpkin. While everyone was busy with his or her creation a drill suddenly passed by. The drill was used to create holes into the pumpkin to give the pumpkin some special effects when lighted. At the end of the activity various sweet, beautiful and frightening pumpkins arose, especially when lighted in the dark room.

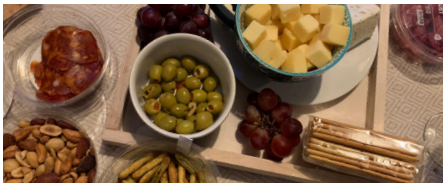
LATEX WORKSHOP

Education for students; by students! One of Mollier's key principles is to share knowledge within the community. Following last year's workshop initiative, we organized an educational evening on academic typesetting using LaTeX. Hosted by Eugene, Mollier's education officer, the event brought together a group of motivated students, both offline and online. We were excited to see some new members from Building Physics and Services, as well as students from Structural Engineering and Design. The workshop kicked off with an introductory presentation, followed by a practical hour where we explored the basics of LaTeX and structured a report in real time. Halfway into the workshop, Eugene ambushed everyone with a challenge that put their newly acquired skills to the test. By the end of the evening, everyone was equipped with a report template that they could use during their studies. We are hoping to see some beautifully structured reports in the near future! This was a very fun workshop to host! We are certainly looking forward to what's coming next; and we suggest that you keep an eye out as well!



MOLLIER PLAYS AMONG US

When the days started to become shorter and the weather got colder, some Mollier members and Alumni gathered online to play some intense games of 'Who is lying?'. Or, in other words, who is the imposter? The game Among Us certainly showed the stealth of some of our members, while others took a turn to test their persuasion skills. In conclusion, were looking forward to seeing some more amazing plays on the next online game night!



RICHARD'S BIRTHDAY BINGO

Richard's 157th birthday was celebrated on the 27th of November with a bingo. The bingo was virtual but most gathered as much as possible for the evening. With drinks and bites at the ready it was time to explain the rules. From the start (nearly) everyone was concentrated on the explanation. This was highly important to make sure you don't have to sing a song as this is the habit for a false bingo. Even though the tempo of the calls was speeding up no one had to show their amazing singing talent. In the prize pool to play for were socks, drinks and coupons, something for everyone. These were awarded for the first row and the full card. The winners were Kim, Maud, Marc, Júlia, Laurens and Meghana. With the drinks and bites disappearing steady but smoothly the evening proved to be a very entertaining one.

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Ice Breaker
Sil Schaars

Hi everyone! My name is Sil and I am 21 years old. I live in Eindhoven for about three years now, but every weekend I go home to my parents who live in a village called Gendt, nearby Nijmegen. I went to the Montessori College in Nijmegen during high school to finish a degree in VWO. During high school I had absolutely no idea what study to choose. Due to my broad interest in different fields, I chose Sustainable Innovation which allows you to do many electives to broaden your knowledge. I finished my bachelor Sustainable Innovation last year, and I am doing a double degree consisting of the two studies Innovation Sciences and Building Physics and Services. In my bachelor, I was really interested in the BPS courses, but also my program Sustainable Innovation interested me. Therefore, I choose to do both master programs, which in my opinion really fit together as sustainability is also an important concept in the Built Environment, and especially in the Building Physics and Services disciplinary. I hope to connect the two studies in my master thesis in which I would like to focus on a project both about sustainable innovations and building physics. In my bachelor thesis, I focused on the potential of hydrogen for mobility purposes in the Netherlands, which was quite an interesting project. Connecting this with hydrogen use within the built environment would be even more interesting to consider during my masters.

I have always played field soccer, but I joined Totelos last year which is the futsal association. Unfortunately, our matches for the coming weeks are canceled due to COVID-19, and I am not sure when we will be able to play again.

Another hobby, that I am not able to do due to this COVID-19 outbreak, is traveling. I really enjoy discovering nature, the sun, and the food of other countries (even though traveling is not sustainable). In 2018 and the beginning of 2020 (before COVID-19), I went to Gambia, Africa. These trips were very interesting as you are confronted with poverty which is quite shocking when considering we are born with so much luxury. The way the Gambian lived was even more impressive, this country is also called the smiling coast, which was definitely the appropriate description of the country. There is not much criminality and people are helping each other where they can, and are satisfied with the life they have. The positivity and satisfaction they have in their lives is an eye-opener to become more satisfied with your 'luxe' life yourself.

One other thing I like to do, which is still possible nowadays, is cooking. I like to try new recipes and try meals without meat, even though I am not a vegetarian I try to minimize the amounts of meat consumption and try new meat replacements or recipes without meat (so if you have a delicious vegetarian meal, let me know).

In the future, I would like to have a job that includes both the theory from innovation sciences about sustainable innovations and how to implement these, combined with the technical aspects of building physics and services. Even though the technique could work optimally, society should still be willing to implement such an innovation. And the other way around, even though society is willing to invest in sustainable innovations, the technique should be developed first. I think having a background in these two disciplines will help me to understand the climate problems better, and I hope I can make a change. ■

Modified Mixture Designs for Self Compacting Concrete

prof. dr. ir. H.J.H. (Jos) Brouwers
Q. (Qingliang), Yu, MSc
Dr. A. (Arno), Keulen

Author
D. (Daria) Zendri, MSc

INTRODUCTION

In the past two decades, it became evident how the industrialization and its speed are not sustainable for the environment. To cover the building sector's demand, a large quantity of concrete is produced yearly, making it the most used construction material worldwide. As a major component of concrete, large amounts of Portland cement are consumed for concrete manufacturing, together with other natural resources. About 1.5 tons of raw materials are consumed for each ton of cement produced and, for the same amount, 120 - 160 kWh of energy is necessary [1]. Moreover, according to data from the U.S. Geological Survey, in 2017 the world production of Portland Cement was approximately 4.2 billion tons [5]; as reported by the World Business Council for Sustainable Development, the manufacturing of 1 kg of cement clinker generates around 0.87 kg of carbon dioxide [2] and it is estimated that the emission of CO_2 for the production of Portland cement clinker accounts for 7% of the yearly total emissions [3] [4].

CRH is a worldwide leading company for the production of building and construction materials, mainly located in Europe and North America. The company manufactures and distributes a diverse range of superior building materials and products for use in the construction and maintenance of infrastructure, housing and commercial projects. Their materials and products are used extensively, in construction projects of all sizes, all across the world. Structural Concrete Belgium (SCB), a CRH Company, is a market leader in Belgium and is specialized in the production of high quality prefabricated concrete elements, e.g. façades and flooring.

The research regards prefabricated facade sandwich panels produced by SCB, which consists of various material layers: inner concrete envelope, insulation material and outer envelope. The current mixture of concrete that composes the sandwich panels consists mainly of raw materials: CEM I, limestone powder, coarse and fine limestone, coarse and fine sand and superplasticizer. This leads to a high impact on the environment. Moreover, the facade panels can sometimes present crazing, that develops on the surface at early age. Crazing can initiate in both hardened and fresh concrete as a result of volume changes. In this project, the crazing is believed to be caused by either shrinkage or thermal stress, which will be the parameters under investigation.

METHODOLOGY

The performance of concrete is greatly affected by the type and degree of packing of its constituents, the so-called particle packing. The particle packing can be optimized through a particle packing model, an analytical model that calculates the overall packing density of a mixture based on the geometry of the combined particle groups [5]. The first step was, hence, to optimize the particle packing model of the concrete mixture used by SCB. The second step was replacing Ordinary Portland Cement (OPC) with Ground-Granulated Blast-Furnace Slag (GGBS). This can have both technical and environmental benefits. In total, six mixtures were produced. The first, M0, is the one used by SCB. The second mixture, M1, is the optimized mixture according to the particle packing model, keeping the same ingredients as M0. For M2 and M3, 10 and 20% of CEM I was substituted with GGBS, respectively. For M4 and M5, 22 and 44% of CEM I is substituted with CEM III.

The research questions are therefore two, divided based on technical and environmental aspects:

A. What is the optimum mixture design, replacing Portland cement with different Supplementary Cementitious Materials to overcome cracking and, at the same time, maintain required final concrete performance?

B. What is the environmental benefit of an optimized mixture design compared to the reference mixture?

The resulting mixtures were tested both in fresh- and hardened-state. As for the fresh-state, the parameters under investigation are density, slump-flow and V-funnel flow time; for hardened-state concrete, compressive strength, autogenous shrinkage, drying shrinkage and crazing investigation under high temperature were performed. Moreover, a Life Cycle Assessment was performed, in order to assess the environmental impact of each mixture. For this study, two indicators are considered: embodied energy (EE), that refers to the sum of all the non-renewable energy required to produce any goods or services, and Global Warming Potential (GWP), which is the emissions released by mankind. Moreover, the Environmental Cost Indicator (ECI) was calculated. The ECI summarizes all the environmental effects on one score and it weights all the relevant environmental impacts that arise during the lifecycle of a product and represents the environmental shadow price of a product or project, from cradle to grave.

RESULTS AND DISCUSSIONS

TECHNICAL PERFORMANCE

FRESH STATE DENSITY

The density of each mixture was measured at fresh-state. The density target according to SCB is between 2390 and 2490 kg/m³. The reference mixture M0 has a density of 2440 kg/m³. When the particle packing of a mixture is optimized, the density is higher, which is shown by the optimized mixture M1, whose density is 2459 kg/m³. When slag is added in a mixture, the concrete density is generally lower. As shown in Figure 1, M2, M3, M4 and M5 have lower density compared to M0 and M1, with 2434, 2430, 2393 and 2417 kg/m³, respectively.

SLUMP FLOW AND V-TUNNEL TIME

Slump flow is used to assess the flowability and the flow rate of Self-Compacting Concrete. The slump flow of concrete mainly depends on the amount of superplasticizer (SP) in the mixture. As Figure 2 shows, a mixture

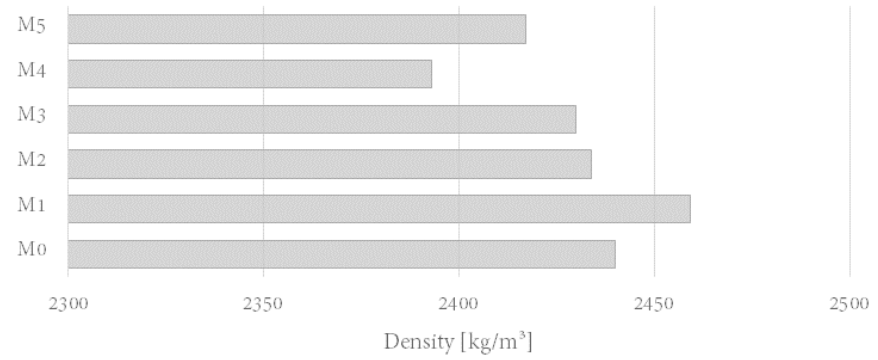

Figure 1. Densities of tested mixtures

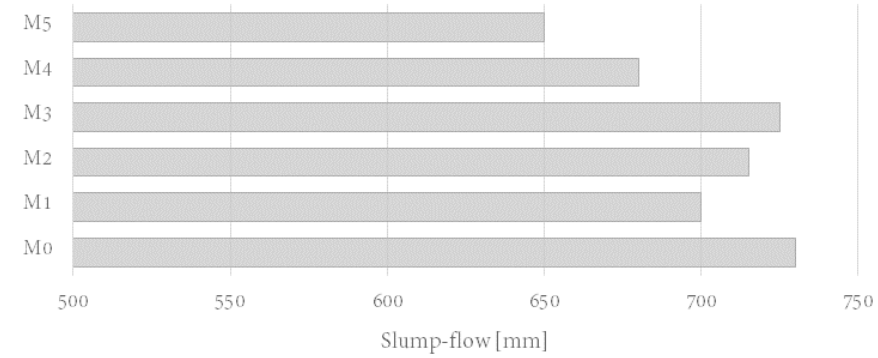

Figure 2. Results of slump flow tests for different mixtures

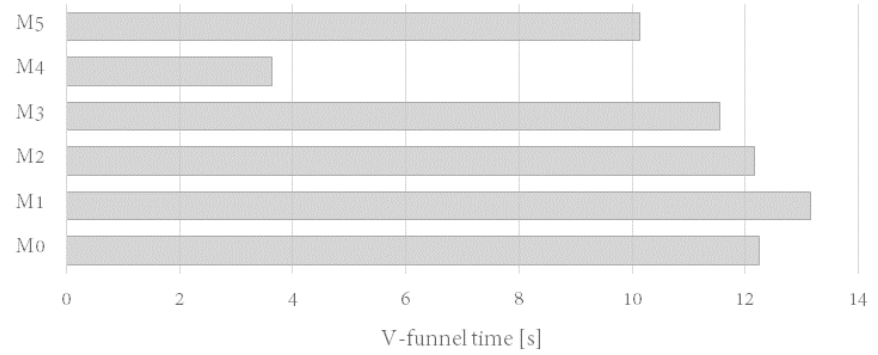

Figure 3. Results of V-tunnel time, tested for different mixtures

with a higher amount of SP have a higher slump flow, while mixtures with lower SP have a lower slump flow: M0 and M1, which SP content is 4.90 and 4.82 kg/m³, have a slump flow of 730 and 700 mm, respectively. M2 and M3, which SP content is 5.02 and 5.00 kg per cubic meter, have a slump flow of 715 and 725 mm, respectively. Finally, M4 and M5, which SP content is 3.95 and 3.94 kg per cubic meter, have a slump flow of 680 and 650, respectively.

V-funnel time is used to assess the viscosity and filling ability of Self-Compacting Concrete. Generally, for this type of concrete, a flow time of 10 seconds is considered optimal. The results of the V-funnel flow time test is depicted in Figure 3. M0, M1, M2, M3 and M5 have similar results, with 12, 13, 12, 11 and 10 seconds, respectively. M4 has a very high flowability, with 4 seconds. Superplasticizer and water have a close relation in the workability of mixtures. M0, M1, M2 and M3 have good workability, both in slump flow and V-funnel. M5 have a good V-funnel value. nevertheless, the slump flow is abundantly lower than the target of 700 mm. M4 has an excessive flowability and a very low value for slump flow. By adjusting the water and SP content of these two mixtures, good results for both slump flow and V-funnel can be achieved.

HARDENED STATE

COMPRESSIVE STRENGTH

The development of compressive strength of the different mixtures is shown in Figure 4. At the age of 1 day, the highest compressive strength is given by M1, the optimized mixture. The second highest compressive strength is given by M0. As expected, the mixtures with slag content, M2 to M5, have a lower compressive strength at early age, with decreasing strength when the amount of slag increases.

However, changes are noticed on day 28. The compressive strength of M2, M3 and M5 increases respectively, by 17%, 13% and 20% compared to day 7. On the contrary, the compressive strength of M0 and M1 have a lower gain, with 9% and 12%, respectively. When PC reacts with water, it forms calcium silicate hydrate (CSH) and calcium hydroxide $Ca(OH)_2$. CSH is a glue that provides strength to the concrete and holds it, while $Ca(OH)_2$ is a by-product and does not contribute to the strength of concrete. When slag is used as part of the cementitious constituent in concrete, it reacts with water and $Ca(OH)_2$ to form more CSH gel and increases the strength [6]. Since the pozzolanic reaction is slow and depends on the calcium hydroxide availability, the strength gain takes a longer time for the GGBS concrete [7]. In general, the results show that, for early strength, the mixtures containing GGBS have a lower compressive strength. Nevertheless, at a later age, the mixtures with GGBS, namely M2 to M5 gain more strength compared to M0 and M1.

DRYING SHRINKAGE

Drying shrinkage refers to the reduction in concrete volume and is caused by the evaporation of internal water in hardened concrete. The drying shrinkage was measured on 400x100x100 mm³ specimens by means of a length

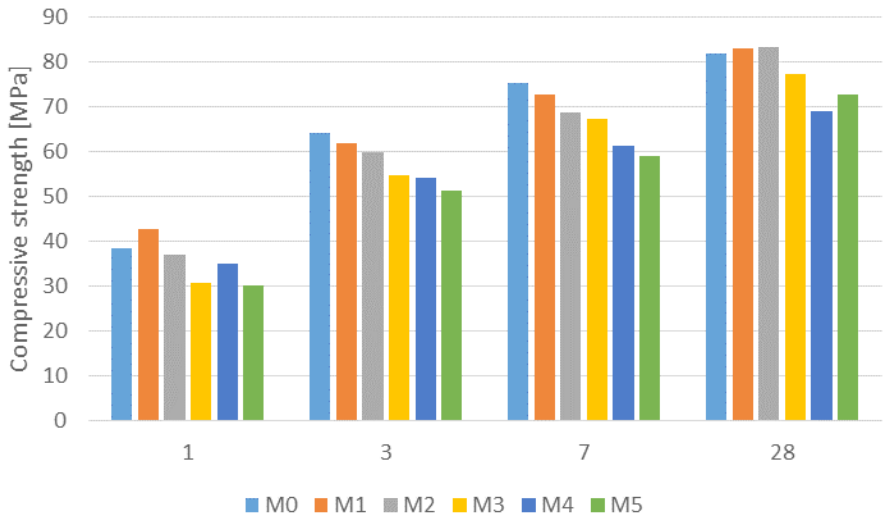

Figure 4. Compressive strength of the six different mixtures at Day 1, 3, 7 and 28

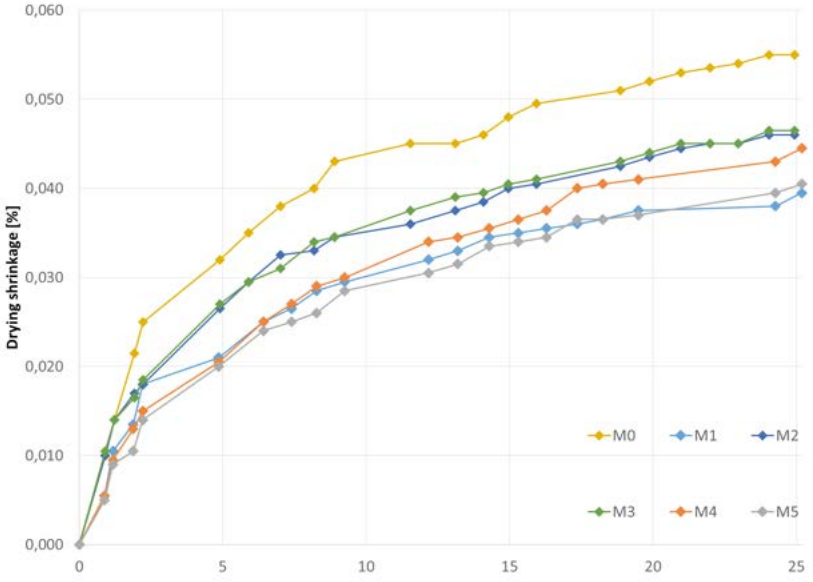

Figure 5. Drying shrinkage for different mixtures

comparator, for 25 days. The results of drying shrinkage are shown in Figure 5. The mixture that shows the highest value of shrinkage is the reference mixture M0. The best performing mixture is the optimized mixture M1. When the particle packing of a mixture is optimized, in fact, the drying shrinkage is reduced, since it is roughly proportional to the volume of cement paste in the concrete [8].

The drying shrinkage of concrete is affected by the type of materials used in the mixture. According to the literature, when cement is replaced by GGBS, the drying shrinkage increases [9]. As shown in Figure 5, the optimized mixture M1 has the lowest shrinkage among the six mixtures. When part of cement in M1 is replaced by GGBS, the drying shrinkage increases. M2 and M3 show higher shrinkage compared to M1 and the higher the GGBS content, the higher the shrinkage. M4 and M5, also show higher shrinkage compared to M1. However, in this case, the mixtures with a higher amount of slag, M5, has lower shrinkage, compared to M4.

AUTOGENEOUS SHRINKAGE

Autogenous shrinkage refers to the reduction of apparent volume or length of cement-based materials under sealed and isothermal conditions. The autogenous shrinkage was measured on 400x100x100 mm³ sealed specimens by means of an electronic displacement transducer; thermocouples were used to measure the temperature change. The autogenous shrinkage test was performed for 18 days.

As shown in Figure 6, during the first day of measurements, the three mixtures have a similar autogenous shrinkage. Between day 2 and day 6, the lowest autogenous shrinkage is shown by M0, followed by M3 and M2, which shows slightly higher shrinkage. After the 6th day of measurements, the autogenous shrinkage of M3 increases substantially, becoming the mixture with the highest shrinkage among the three. M0 and M2 show a similar shrinkage curve, with M0 presenting slightly less shrinkage. The highest autogenous shrinkage of M2 and M3 compared to M0 is given by the fact that when cement is replaced by GGBS in a mixture, the autogenous shrinkage increases. Generally, the higher the content of GGBS, the higher the autogenous shrinkage [10]. The specimens for M1, M4 and M5 were improperly sealed, hence the results could not be considered.

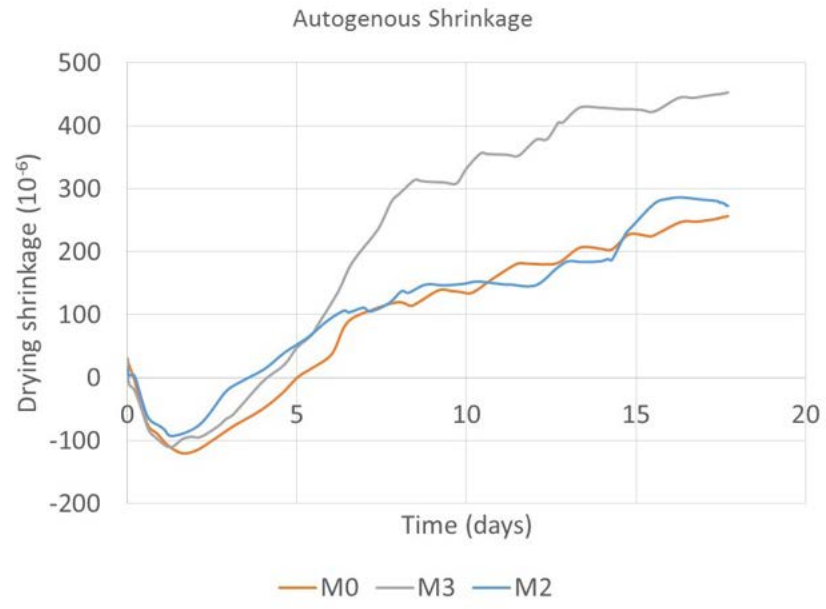

Figure 6. Autogenous shrinkage in the mixtures.

CRAZING INVESTIGATION

To investigate which mixture has a better performance in terms of crazing, the specimens were heated in a furnace at 200°C, and the crazing patterns on the surface were analyzed. In order to reduce crazing, Portland cement was replaced by slag. When slag cement is incorporated in a concrete mixture, less heat is generated, and thermal stress is reduced. As expected M0, the reference mixture, shows extensive crazing on the whole surface of the cylinder, with closed pattern and thick lines.

By optimizing the reference mixture, crazing becomes less evident, as shown by mixture M1. The crazing has an open pattern, thinner lines and covers the surface of the cylinder only partially.

M2 and M3, which replace CEM I in the mixture by respectively 10% and 20%, both show minimal crazing, concentrated in a few areas, with a narrow pattern and very thin lines.

M4 and M5, which replace CEM I in the mixture by respectively 22% and 44%, hence have a slag content of 10% and 20%, also show little crazing, only in delimited areas (Figure 7).

ENVIRONMENTAL PERFORMANCE

EMBODIED ENERGY

M0 has the highest value for EE, caused by the high amount of CEM I in the mixture. M1 shows the benefits of the particle packing optimization: by lowering the amount of CEM I, the embodied energy is lower compared to M0. M4 and M5 follow, where the combination of CEM I and CEM II increase the embodied energy. The lowest values for EE correspond to M2 and M3. For both mixtures, part of the CEM I content was replaced with GGBS, which has an embodied energy equal to 32% of the embodied energy of CEM I (Figure 8).

GLOBAL WARMING POTENTIAL

The highest impact regarding CO_2 emissions is given by M0. The reference

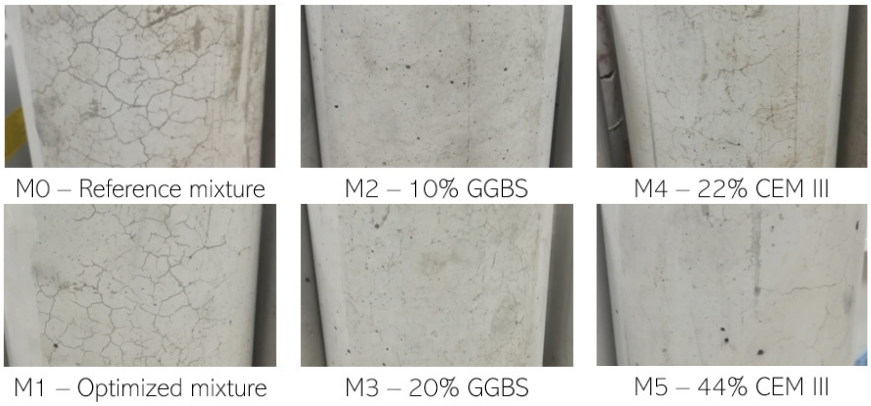

Figure 7. Crazing on the cylinders after being heated to 200°C

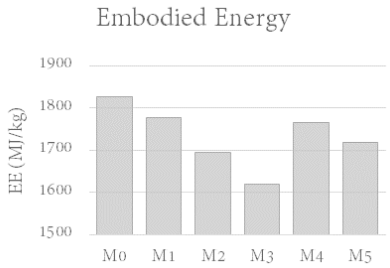

Figure 8. Embodied energy for different mixtures

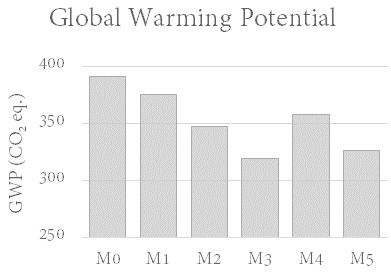

Figure 9. Global warming potential

mixture, in fact, has the highest content of CEM I that, according to the LCI, is the materials with the largest impact on Global Warming Potential.

The second highest value corresponds to the optimized mixture, M1; this mixture has less CEM I content compared to the reference mixture, hence the lower value. M4 has the third-highest value; despite this mixture having a lower SP content compared to M2 and M3, the combination of CEM I and CEM III makes the GWP higher. Followed by M2, M5 and M3, which contain the highest amount of by-product, lowering the carbon footprint of concrete.

It can be noticed, nevertheless, that having the same amount of slag results in similar GWP values: M2 and M4 have similar results, as well as M3 and M5 (Figure 9).

ENVIRONMENTAL COST INDICATOR

The Environmental Cost Indicator results follow a similar trend to the Global Warming Potential. The highest ECI value is displayed by M0. As for GWP, M0 has the highest content of CEM I that, according to the LCI, is the materials with the largest ECI value. The second highest value belongs to M1. This mixture contains less CEM I compared to the reference mixture, hence the lower value. M4 has the third-highest value. Despite this mixture having a lower SP content compared to M2 and M3, the combination of CEM I and CEM III makes the ECI higher. Following M2, M5 contains the highest amount of by-product, which lowers the overall impact on the environment (Figure 10).

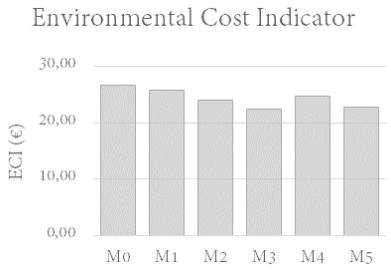

Figure 10. Environmental cost indicators of different mixtures

CONCLUSIONS

The two research questions can, therefore, be answered as follows:

A. Among the six mixtures, M2, which contains 10% GGBS, provides the best results. The high temperature investigation shows very little crazing compared to the reference mixture M0; the compressive strength on day 1 is slightly lower than the one of M0, but at the 28th day it becomes stronger. M2 shows 16% less drying shrinkage compared to the reference mixture and lower water absorption during the first six hours. M3 also provides good results. It shows very little crazing and the compressive strength is good at day 1. The drying shrinkage of M3 is 15% than that of M0, and it absorbs 44% less water than the reference mixture. M4 and M5 do not reach the minimum target for slump flow during the fresh state, which is fundamental for Self-Compacting Concrete.

B. The optimization of the reference mixture leads to environmental benefits. After the mixture is optimized, the CEM I content is lower, which leads to a lower impact in terms of embodied energy, lower carbon emission and net freshwater usage. The replacement of CEM I with Supplementary Cementitious Materials is the key to further lower the environmental impact of concrete mixtures. SCMs materials like limestone powder and GGBS have a lower energy and carbon footprint, being by-products of other industrial activities. M2, M3, M4 and M5 all show environmental benefits regarding Embodied Energy, Global Warming Potential and overall Environmental Cost Indicator. ■

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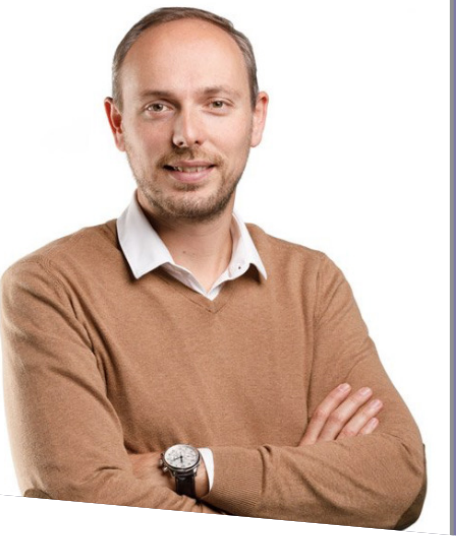

Integrating Pedestrian Wind Comfort in Early Design Process

Eric Terry
Managing director of Actiflow

Cities are becoming denser. We build more and more high-rise buildings, but these buildings typically induce high wind speeds on pedestrian level. As such, high buildings can reduce pedestrian wind comfort and the attractiveness of an entire neighborhood, but they can also lead to dangerous situations, especially for elderly or physically vulnerable people. Therefore, it is important to reduce high wind speeds in public spaces.

In many places, governments and municipalities are starting to understand the important influence wind can have on the quality of life in our cities. However, we now see that wind assessments are mainly used to study existing problems. If assessments are performed in the design phase, they are mainly used to check the impact of a single building or project, when the design is almost finalized.

Wind is a large-scale phenomenon, and therefore it should be taken into account on a large scale in a city. This means that wind effects should not be studied or solved on a building level, but in an entire area or neighborhood (see Figure 1). Moreover, it is important to study the impact of a new development already in an early phase, while it is still possible to change building volumes, the landscape design or the orientation of buildings and streets. In a later phase, when the design of each single building is almost ready, a final check for pedestrian wind comfort can be performed and possible issues can then be mitigated with smaller measures like adding vegetation or small canopies or screens.

At Actiflow, we advise governments as follows:

1. Assess the impact that wind has in your city, but also look at other aspects like shading, sound, heat islands, mobility, air pollution, etc.
2. Determine the critical areas in the city, and consider how the challenges can be solved on a large scale (e.g. open up or densify the urban texture, introduce parks or other landscape elements, determine where high-rise buildings can be allowed, determine the orientation of important streets and corridors, etc.).
3. Determine which quality standards you want to achieve, depending on the local function of the public space.
4. Translate the large-scale solutions and quality requirements into practical guidelines and codes for developers and architects: which building volumes are allowed, how to orientate the volumes, what is the maximum building height, where to place entrances or private outdoor spaces, and how to prove that a building design meets the requirements.

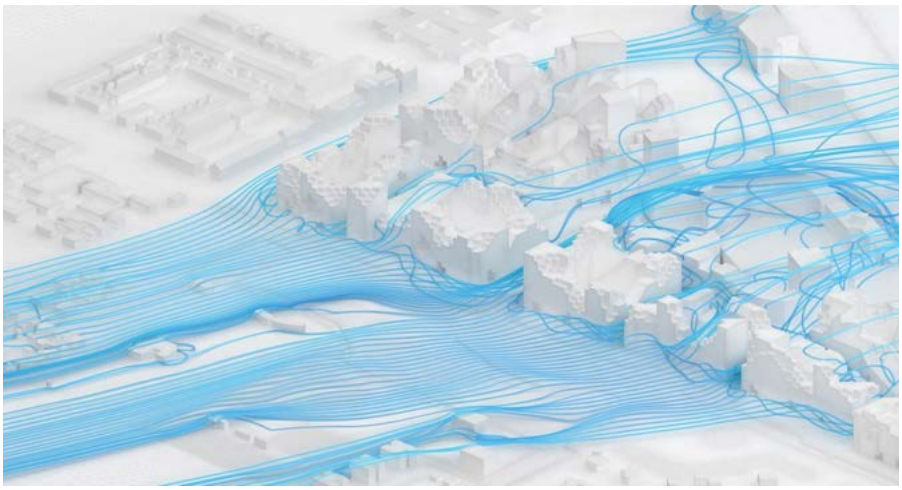

Figure 1. Illustration of streamlines indicating the path of the wind

If good guidelines and rules are in place, developers and architects can check their concept designs for compliance. By involving wind assessments during the design process, possible local issues can be identified in an early phase and the impact of a design modification can easily be assessed. When the building design is fixed, a final check can be performed to show compliance with the norms set by the government.

CASE STUDY

Actiflow performs around 100 studies per year to advise governments, architects and developers about wind in the urban environment. An example of a wind study as performed by Actiflow, is the wind study for the Amstel III area in Amsterdam, performed according to the Dutch NEN8100 norm, using CFD computer simulations.

In a CFD study, a three dimensional computer model is built of a part of a city, and OpenFOAM is used to simulate the wind behavior in the entire city area for varying wind directions. The simulation results are then combined with the local wind statistics, in order to produce maps with local wind hindrance classes and local wind danger classes.

Table 1. Definition of wind hindrance classes

Chance of exceedance (%) (Local wind speed > 5 m/s) (the numbers of hours per year)	*Quality class*	*Activities*		
		Walking	Strolling	Long-term sitting
<2.5 %	A	*Good*	*Good*	*Good*
2.5 – 5 %	B	*Good*	*Good*	*Moderate*
5 – 10 %	C	*Good*	*Moderate*	*Poor*
10 – 20 %	D	*Moderate*	*Poor*	*Poor*
>20 %	E	*Poor*	*Poor*	*Poor*

The wind hindrance classes are defined by the probability of exceeding a local wind speed of 5 m/s. From a functional point of view, the wind classes describe whether a certain location is suitable for "staying for a long period in time", "strolling" or "walking through" (see Table 1).

To determine the risk for wind danger, the NEN-8100 norm looks at the probability of exceeding a local wind speed of 15 m/s.

BACKGROUND

Amstel III is an area of approximately 1 km² at the south-east of Amsterdam. Currently, the area is mainly occupied by offices. The average height of the current buildings is roughly 25m, and the buildings typically have a square footprint (see Figure 2).

The municipality of Amsterdam has the desire to transform this area into a lively urban district with mixed residential, office and recreational use. Between now and 2027, roughly 5.000 new houses will be realized, together with shops and new office spaces. Obviously, the municipality also envisions a comfortable outdoor space in this area.

To realize the goals of the municipality, a significant amount of building volumes will be added to the area, leading to the introduction of high-rise buildings and a denser urban fabric. In the early planning phase, the municipality wanted to know if this increase in building volume would lead to problems concerning wind.

RESULTS

In Figure 3, the wind hindrance map is shown for the simulated area. The results are shown in a cross section which is 1.75m above ground level.

In the map, it can be seen that there are several significant regions of wind class D and E, which have to be avoided in public areas. An important reason for these problematic areas is the orientation of the existing street plan. A large part of the streets is straight and SW-NE oriented. As the dominant wind direction in the Netherlands is SW, the wind from this direction can accelerate along the streets and cause problems at the corners of several buildings.

A second reason is the addition of high-rise buildings. The wind that flows over the older (lower) buildings hits the façade of the high-rise buildings and then causes wind hindrance on pedestrian level through the downwash effect.

On the other hand, there are also enough regions with wind class A and B, which are perfectly suited for outdoor sitting and outdoor activities.

RECOMMENDATIONS

Based on the results of the wind study, the following recommendations are formulated:

- As the dominant wind direction is SW, it is advisable to have rather low buildings in the SW part of Amstel III, and to slowly increase the maximum height of the buildings towards the NE.
- Critical buildings should be placed on a plinth or should have canopies that reduce the effect of the downwash on pedestrian level.
- Preferably, buildings should not be placed in a square grid, but rather in an irregular pattern, to avoid accumulation of wind from the SW.
- Design the public space as much as possible in accordance with the governing wind classes.
- Make use of natural elements like trees, hedges and other vegetation to break down the wind as much as possible.

Based on this study, the city of Amsterdam formulated guidelines and requirements for real estate developers in the Amstel III area. Each developer now has the obligation to prove in an early design phase that the design of their building(s) meets the requirements in terms of wind comfort. This is where CFD or Actiflow helps managing pedestrian level comfort in the built environment. ■

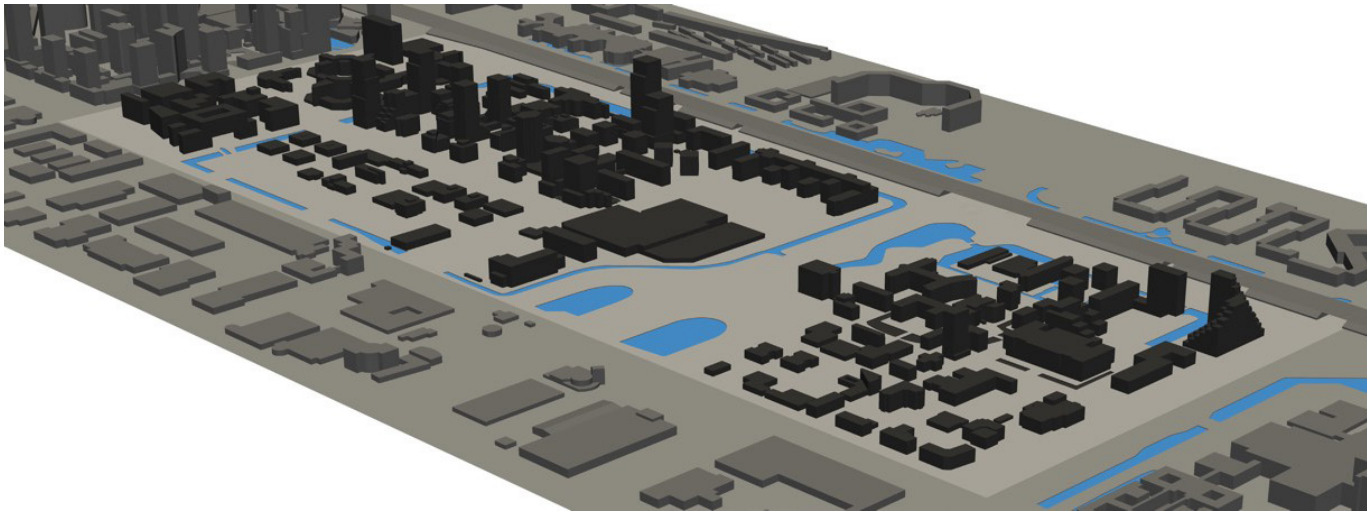

Figure 2. Overview of the Amstel III region near Amsterdam

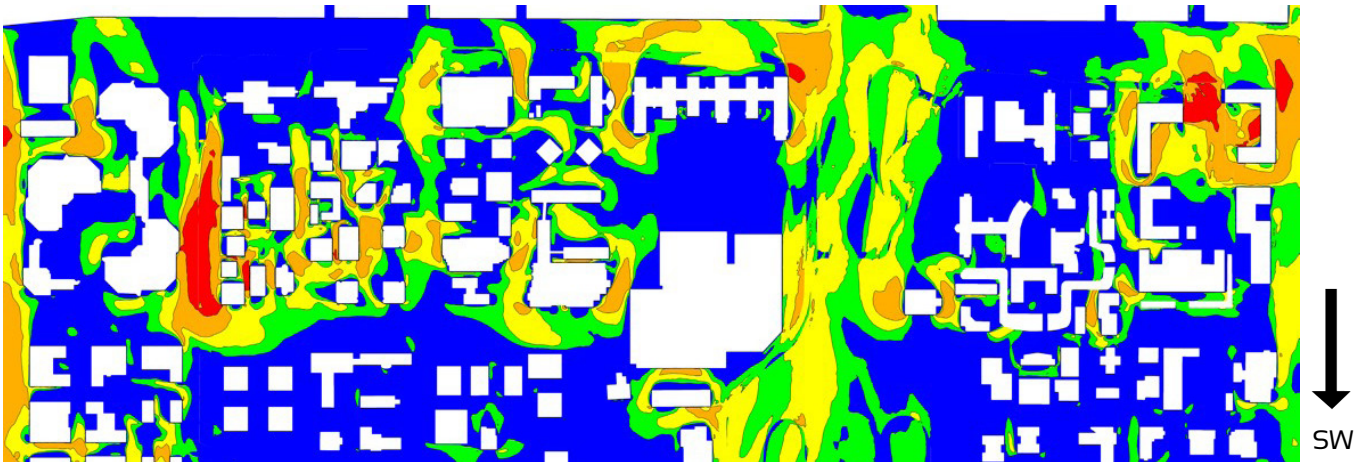

Figure 3. Wind hindrance classes in the Amstel III region

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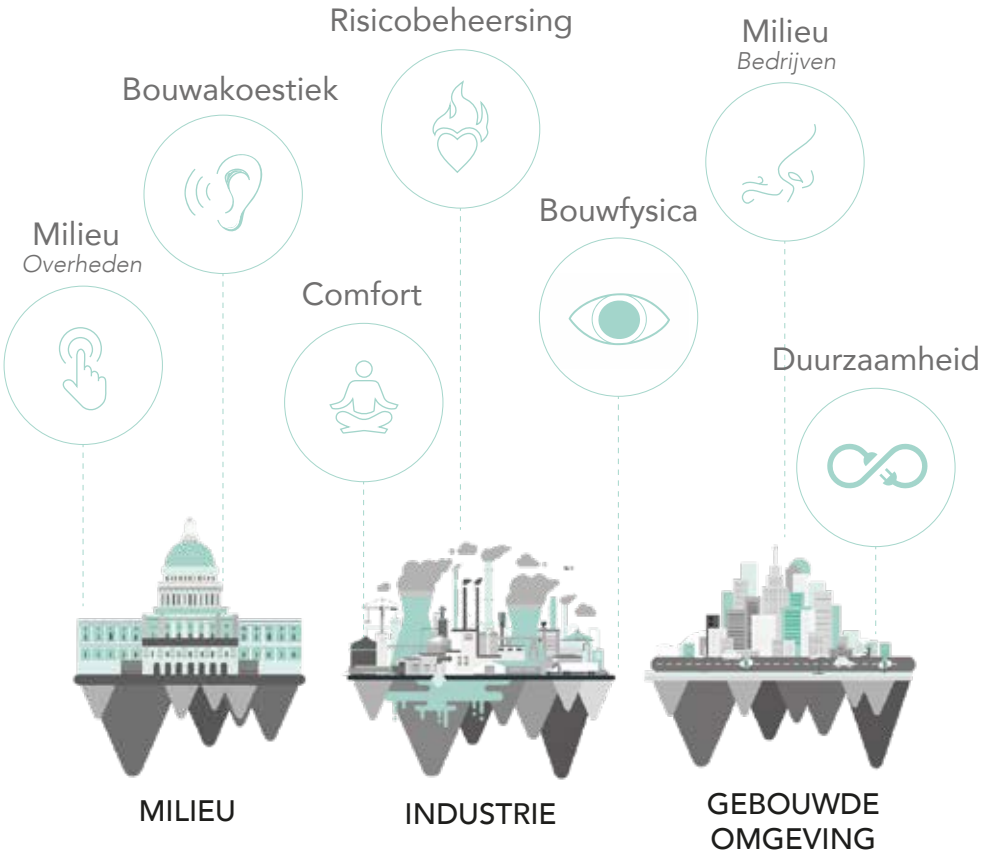

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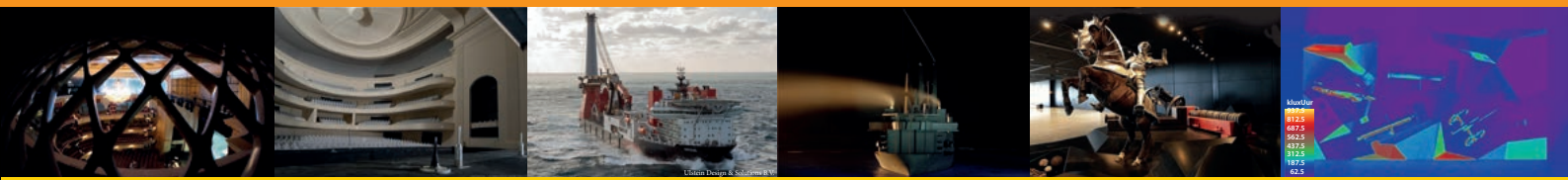

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The Design of a Circular Bio-based Air Handling Unit

Author
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Supervisor
Prof. ir. W. (Wim) Zeiler

INTRODUCTION

Buildings are globally responsible for around one third of the energy use, half of the material consumption, and one third of the greenhouse gas emissions [1,2]. An efficient way to increase sustainability is to close the material loop and to adapt a circular approach for used and bio-based materials. Building installations have a high operational and material impact within the built environment. Within this research, the possibility to decrease the environmental impact of HVAC systems has been explored by applying a circular strategy [4].
The research question within this research was:
How can a circular bio-based HVAC system be designed to reduce the life-cycle energy of HVAC systems?
Within this research, an Air Handling Unit (AHU) was analyzed, as these material intensive systems are used vastly within large buildings.

METHODOLOGY

The research started with a problem analysis, showing a need for a circular bio-based AHU. Afterward, a case study was performed to determine the elements within an AHU which have the highest Embodied Carbon (EC). Three different concepts have been developed for these three elements. This has been done with the methodical design methodology [3]. Thereon, a Life Cycle Analysis has been performed for the current design of the three elements, a recycled version of the three elements, and the new designs of the three elements. Then, a conclusion was drawn whether the new circular bio-based variants of the elements were an improvement compared to the current system.

CASE STUDY

Within the case study, the AHU of Kropman Breda has been used as a reference. Within the AHU, the heat recovery, cooling and the cabinet itself have the highest EC, of 32%, 21%, and 14% respectively. This is mainly due to the high amount of aluminum used, accountable for around 50% of the total EC.

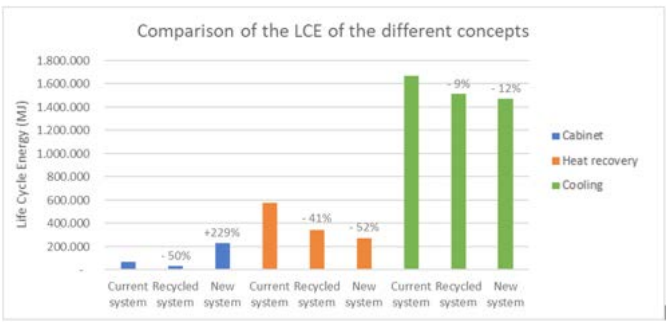

Figure 1. The LCE of the different concepts

Table 1. Overview of the improved design concepts

		Option 1	Option 2	Option 3
Cabinet	Type	Post & Beam	Post & Beam	Post & Beam
	Corner materials	Recycled plastic	PLA - waxed	PLA - waxed
	Insulation	Aerogel	Rockwool	Hemp
	Finishing	PLA - waxed	Wood	Compressed hemp
Heat recovery		**Option 1**	**Option 2**	**Option 3**
	Type	Horizontal flat panel	Condensation wheel	Rotary wheel
	Recovery material	Recycled plastic	Aluminum	PCM
	Surrounding material	Recycled plastic	Recycled plastic	Recycled plastic
Cooling		**Option 1**	**Option 2**	**Option 3**
	Type	Evaporative cooling	Adiabatic cooling	Cooling coil
	Cooling material	Excelsior	Corrugated cardboard	Recycled plastic
	Surrounding material	Recycled plastic	Recycled plastic	Recycled plastic

DESIGNS

The designs have been developed with the help of a morphological overview. A focus was put on the basic principle of the elements, combined with the materials which needed to be used. The different design options were evaluated with the help of the Kesselring method [3] and improved, with the help of two stakeholders. The improved design options can be found in table 1. From this, it was concluded that the third options were every time the best design option.

LCA

In order to check whether the new designs were an improvement compared to the original system, an LCA was performed. Figure 1 gives an overview of the results of the Life Cycle Energy (LCE). From this, it was concluded that the new systems of the heat recovery and the cooling would be an improvement. However, the new version of the cabinet did not improve sustainability due to the increase in material use.

CONCLUSION

To conclude, the possibility to develop a circular bio-based AHU was explored. The research showed that it was not possible to develop a fully bio-based AHU due to the properties of the bio-based materials. However, by designing a AHU with a cabinet of recycled materials, a PCM heat recovery, and a recycled plastic cooling coil, the Life Cycle Energy could be reduced by 25%. This shows the potential of creating a circular bio-based AHU. ■

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Alumni at Work: Green Light District

Author
Ir. J.W.P. (Jill) Vervoort

I was asked to give you all a bit of inside information on what I am working on lately. For those of you who want to know who is writing this: I am a village girl (born in America the Greatest, 40 km east of Eindhoven), I studied at the TU/e for 7 years, of which I was part of Mollier the last 4. Finally, I left the university with two master's degrees, which is already 2,5 years ago, I just realized. I started working at De Groene Grachten right away. We are an engineering/ consultancy company with expertise in retrofitting historical buildings, and we show every day how our building heritage can be sustained whilst fighting against climate change. Yeah, I really just wrote that, and believe it or not, we truly serve this goal.

Sustainability is actually my main guideline. For example, last year September I started a new adventure: moving to the 'big' city of Amsterdam and making sure my central city apartment would be natural gas free by 2020. Probably you are wondering: why so? And what is so special about this? Let me tell you a bit more. Since 2019 there are a bunch of non-profits, companies, and researchers working together in the so-called foundation 'The Green Light District' (GLD). Of course, this is more than just a nice pun. Namely, this bottom-up approach is transforming the populous and most visited square kilometers in Europe into a future-proof, sustainable, and climate adaptive icon of Amsterdam. We show how the energy transition works in the most difficult part of Amsterdam: the historic city center where I live! The foundation has formulated lots of different pilot projects. Perhaps a couple of you are already familiar with the projects we run (most likely if you are connected with me on socials). Nevertheless, I would like to give you a bit more inside information!

PILOT PROJECTS

Within this foundation, my company – De Groene Grachten – has an important role in 5 projects:

1. Sustainable canal house: The sustainable canal house is the birthplace of the entire GLD project. This house has been neglected for years and is located in the middle of coffeeshops, tacky tourist shops, and of course red lights. This house is actually a national monument, dated from 1733 with an extraordinary decorative door piece of 'Admiraal Tromp'. Here, the vision was born to transform this hopeless pile of bricks into an innovative and inspiring sustainable hub to support and stimulate locals to create a sustainable living environment. Next year, 2021, the implementation phase will start.

2. Sustainable shopping street: Pre-Covid 19, the city center was one of Europe's most visited tourist attraction. Even though this image might change after Covid-19, we still want to make a statement by showing visitors how shops are becoming sustainable and spread awareness at the same time.

3. Sustainable building block: Sometimes you forget it whilst walking around in this area, but above pedestrian level there is more life than meets the eye, real people are living there too. Since an entire building block entails many different functions, there is lots of potential to exchange energy, but most of all, to create a collective sustainable energy source.

4. Sustainable quays: The restoration of the quays will probably go down as one of the most complicated and expensive challenges for the city of

Amsterdam. It's not only a challenge, it's also a possibility for creating new sustainable energy sources! We make way for entering innovative techniques within the restoration programs.

5. Sustainable rental apartments: Last, but not least, two rental apartments have been selected as a case study to replace the gas boiler (heat pump vs. infrared). This is mainly an experiment for real estate owners to find out which measures are necessary, how the process works, and what is required from the tenants. So when I got the offer to serve as a guinea pig, I couldn't resist.

NATURAL GAS FREE APARTMENTS

Until September 2019, I was still traveling back and forth between Eindhoven and Amsterdam, telling myself the traveling was not that bad and Eindhoven was the place to be. I was not able to accept I was no longer a student in this city, but how could I resist the unique offer of an apartment in the middle of Amsterdam's city center? The only requirement (besides paying the rent) was becoming an ambassador for the first natural gas free apartment of the rental company by supporting the process, blogging about my experience and collecting data. I got a new heating system: the natural gas boiler was swapped for a heat pump and my radiators were replaced by convectors. Sounds simple right? For us maybe, though there are lots of people who wouldn't know where to start, let alone have the energy to make it work. And this is exactly the point of why we are doing this: showing that it is possible to make an apartment in a monumental building future-proof.

Personally, I really enjoyed the process even though it was for sure not without setbacks. For example, one month I was without heating due to bad planning, which was actually the best setting for throwing somewhat of a housewarming in January (a few alumni might remember, or not). Plus, I learned to take cold showers, which incredibly enough, I am still doing every 1 out of 4 showers. Perhaps I am overdoing this sustainability crusade a bit, though for me it's like a game to live the best sustainable life by pushing the boundaries.

WHAT ELSE?!

The GLD project is definitely not the only thing that is keeping me busy. Actually, that part is almost like a hobby. For work, I am currently involved in about 15 different projects, varying from drawing sustainable roadmaps, determining condensation risk with post-insulation, supporting permit processes, selecting contractors and installers, and getting a grip on circularity for heritage buildings. Besides work, I am part of an advisory committee of a so-called Farm Fund (het boererijenfonds). This fund was brought to life to preserve and renovate historic farmhouses whilst improving the quality of life on the countryside. And guess what, I am representing sustainability during our assessments.

Next to all this, I feel the urge of being connected to people and I feel responsible for preserving the body of thought from my time with Mollier. Therefore, I am part of the alumni board: Schoone Leij. Shamefully enough, our current board is a bit lacking behind in facilitating drinking opportunities. Though we do have this awesome excuse: Covid-19! I'm not sure if this really makes me feel any better. Alright, I've told enough about myself. Now I would like to find out what you all are doing. What do you think? Maybe we should follow Mollier's example and get this Schoone Leij thing going digital?! ■

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Ir. Peter van Mierlo

Project Atlas
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BPS Basics 'Circular Challenges'

Author
Ir. H. (Hajo) Schilperoort

Circularity is often simplified to reduce-reuse-recycle, but what are the challenges while looking at the big picture on planetary level?

PLANETARY BOUNDARIES AND DEFINITIONS

Huesemann & Huesemann [1] define three indicators for circularity on planetary level:

1. All energy comes from renewable sources at or below renewable rates.
2. All materials come from renewable sources at or below renewable rates.
3. Waste (this includes emissions) can only be released at or below the assimilation rate, without negative impacts on the ecosystem or biodiversity.

Circularity aims to keep impacts within planetary boundaries and avoid depletion of resources. We are currently far removed from that point as we overshoot particularly the safe boundaries for biodiversity loss, deforestation, nitrogen and phosphate depositions, and global warming; risking/causing substantial alteration of the Earth System [2].

"Rate" is the keyword in the Huesemann [1] indicators. Overshooting is temporarily possible, but only at the cost of damage, destruction, and depletion. Restoration is sometimes possible, but not all processes are reversible, or not in a linear manner.

Then if this is our global compass, where do we meet problems, what are the circular challenges?

CHALLENGE 1: RENEWABLE ENERGY AND NON-RENEWABLE MATERIALS

One problem is that renewable energy technology so far relies on non-renewable materials, particularly a wide array of (rare) metals for solar, wind, grids, and batteries.

Various reports [3] [4] [5] signal that mining production needs to grow at unprecedented annual rates for 17 metals in the next 30 years to bring about the Paris energy transition, while this does not even take into account the metal use by other industries (such as electronic consumer devices). This is also a geopolitical problem, as Europe has almost no relevant mining and refining capacity of its own.

Metal production is moreover particularly damaging. The Environmental Cost Indicator [6] shows that the "shadow costs" of, for example, 1 kg steel or 1 kg aluminum are roughly 100x and 1000x higher than those of 1 kg concrete (Figure 1) This has a bad name because so many kilograms are used. The ECI is based on a Life Cycle Analysis with 11 monetized environmental impact categories.

Reuse and recycling can help to reduce the demand for virgin metals, but only in the long run, while the renewable energy transition is now (before 2050) needed. Reuse and recycling do moreover not allow volume growth, while the global demand is far exceeding the global supply. The substitution of rare materials in solar, wind, and batteries would help, but without shifting to other limited materials that will then be quickly depleted.

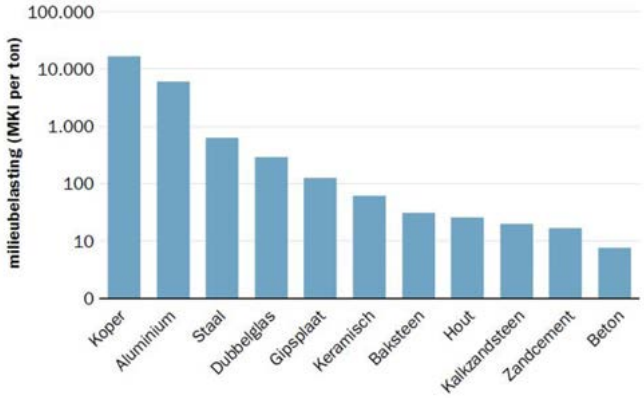

Figure 1. The Environmental Costs (i.e. shadow costs) for common construction materials (image credit: TNO, 2018a)

CHALLENGE 2: ORGANIC AND ECONOMIC GROWTH

The Huesemann [1] definition brings also another problem to light. At some point, we will run out of, or exceed the production output rates of non-renewables. For metals, concentrations get lower, so mining gets more costly and ever more damaging (more common construction materials such as aluminum and steel are for now not endangered in supply). Minerals seem abundant and harmless, but in Asia, a sand mafia steals entire beaches and river banks to supply the particular type of sand grains that are needed in concrete production [7]. Identified fossil fuel reserves are finally available for another 50-150 years [8], but we can use only a very small portion of them to avoid catastrophic global warming.

The only resources that allow ongoing volume growth (and have a low or highly positive ecological impact), are bio-based materials. Their growth is infinite in that the Earth and Sun combined can produce them forever within fertility limitations, but it is not unlimited in terms of production rates. For example, it takes decades to grow trees into maturity. We are limited to the production capacity of sustainably managed forests, that urgently needs to grow. Materials such as bamboo, straw, flax, hemp, reed, and mycelium have considerably shorter cycles and can be implemented without such delay (biocomposites and cardboard may in part replace metals in ventilation systems).

Not just time, but also space is a fundamentally limiting factor [9]. The production of non-food organic materials competes

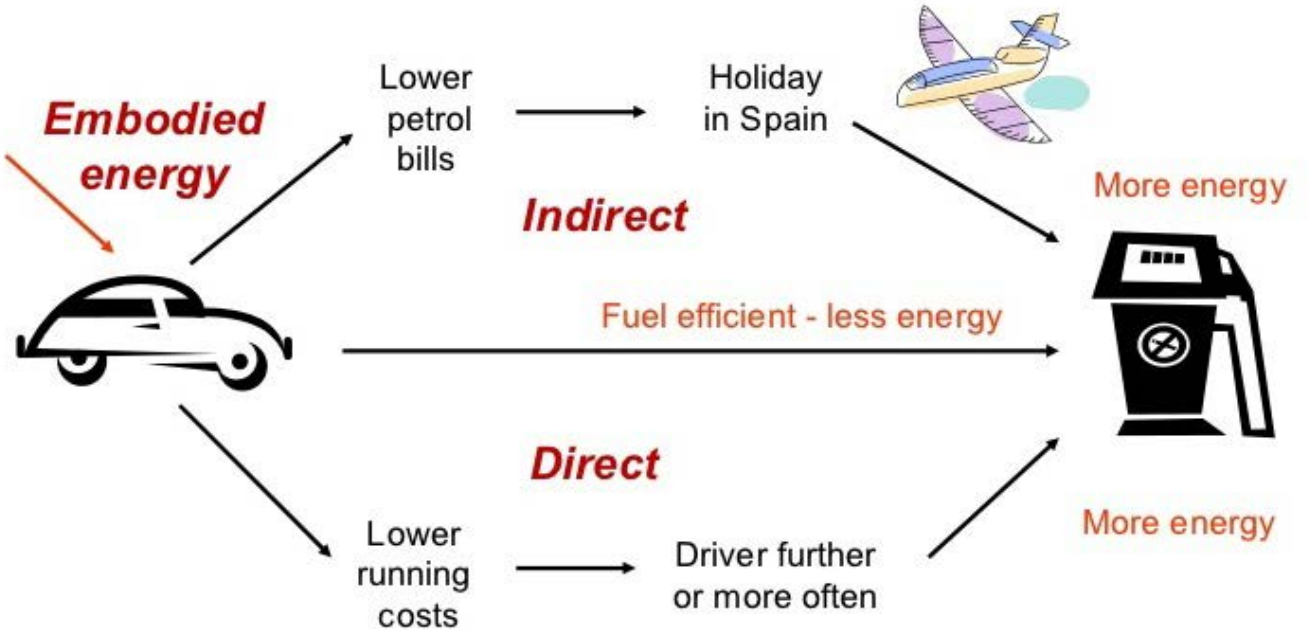

Figure 2. Rebound effects illustrated for a more efficient car. More use is a direct effect (SUV sales also go up). Spending saved money on other damaging consumption is an indirect rebound effect. Meanwhile, the energy goes into producing the car. The same goes for any other type of efficiency gain through innovation, such as space heating, LED lighting, etc. [image source: energypost.eu].

with land claims for (circular) agriculture (particularly meat production requires large areas of land, not to mention its significant contribution to global warming), built-up area, and wild diverse nature [10]. This is an important task for global spatial-temporal planning. Grassland for cattle could be used with changing diets, but in many cases this land needs irrigation and fertilizers for full production.

CHALLENGE 3: SYSTEMIC CHANGES AND CONSIDERATIONS

Technological innovation can play an important role in solving our problems. We need a systemic view though. We are not yet in the advanced stage where innovation creates no problems in other areas ("side effects"). For all the advances in renewable energy technology and capacity, the usage of global fossil energy is also still growing at spectacular rates, in line with "economic growth".

Systemic thinking should also take into account rebound effects, as efficiency gains due to innovation can lead to more consumption, as is illustrated in figure 2. It is never enough to modify one control, effective policies will have to oversee the whole dashboard.

Much will finally depend on simultaneous socio-economic innovation, as the overshoot of various planetary boundaries and the scarcity of time, land, energy, and materials are directly caused by the size (and growth) of global consumption, which puts everything "under pressure". The developed countries have a special responsibility here, as the few rich have a much bigger footprint, per capita and combined, than the many poor countries [11].

A circular economy will have to acknowledge ecological boundaries, and step away from the modern idea of infinite (and even exponential) "growth". A circular economy will also feature Fair Pricing of products and services, including shadow costs for prevention and/or compensation of damage. This creates a level playing field for truly sustainable solutions, that are often considered to be more expensive, but that holds only true when shadow costs are ignored and not paid for (i.e. they are ultimately "paid" by others elsewhere and future generations) [12]. That mix will ecologically and economically change everything. ■

The author is lecturer of the elective Master course 7XC1M0 Circularity in the Built Environment, which is part of the TU/e wide Master Certificate Circular Design in the Built Environment.

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PDEng Project: Intelligent Solar Shading Systems

Author
O. (Oindrila) Ghosh, MSc

Supervisors:
dr.ir. R.G.C.M (Roel) Loonen
Sam Kin

There is an increasing awareness of wellness and health in office and public spaces in the building industry. Research [1,2,3] has proven the importance of daylighting in offices and hence the increased smart use of solar shading systems is observed. Also increasing construction of fully glazed high-rise buildings is the current architectural trend all over the world with little regard to the local climate context. This has resulted in an influx of daylight into office spaces thereby creating a need to be able to dynamically control the amount of light and heat entering the building. There is a plethora of shading systems available in the market that closes or opens according to a specific sensor threshold or they can be manually overridden by the occupant of the office space. This still is not efficient and smart and doesn't improve the quality of the indoor comfort. This is where my project company – Kindow [4] comes in. It is an indoor shading solution and it has two product lines Vertical Blinds (figure 1a) and Roller Shades (figure 1b).

Figure 1. Kindow's product line (a) Verticals (b) Rollers. This PDeng project involves the evaluation of the operational performance of these two products.

Kindow's shading systems uses fabrics with high reflectance values. It utilizes an advanced sun tracking technology that dynamically traces the sun position and senses outdoor sky conditions (figure 2) to modulate the amount of heat and light that enters the space, providing optimal visual and thermal comfort.

Figure 2. Example of Kindow Rollers automatically adjusting shade height according to sun position (left). Fully retracting on a cloudy day (right) to provide better daylight admission and views to the outdoor. [4].

But there are a few problems that Kindow faces as an innovative solution in the solar shading market. They can be categorized as follows:

1. Lack of research in terms of its performance evaluation in varying practical operating conditions as well as benchmarking its operational performance with other available products. Are there further possibilities of improving on the current control strategies?

2. There are thumb rules in the architecture, engineering and construction (AEC) industry like "only exterior shading is useful, because it can actually keep the sun out" [5,6]. Do these assumptions still hold? Such anecdotal assumptions also greatly hinder market integration for innovative solutions like Kindow.

3. It is an integrated system where glazing properties in combination with shade material properties will affect overall performance for varying building design. How can this be co-optimized so that Kindow can better suggest its client on combinations of glazing and lighting with Kindow products for optimal visual and energy performance of the indoor space.

So, these problems that currently Kindow was dealing with became the main objectives for my PDEng project. The way I began approaching this problem was by first assessing Kindow's existing operational performance using a complex co-simulation framework developed by our research group - Building Performance. This was then followed by providing solutions on three categories as follows:

1. *Kindow's strategic research and development:* I carried out simulations for Kindow products for varying client scenarios like changing location and direction and they were compared against products available in the market like a dynamic blind using solar irradiance as a sensor threshold. These studies illustrated that Kindow shades are at least 23% more energy efficient than their conventional indoor counterparts. Furthermore, it also leads to the development of different control strategies for both roller shades and vertical blinds. For roller shades, it was in response to changing façade orientation. Whereas for blinds they were in response to occupancy schedules

2. *Myth breakers:* The existing thumb rule that external shades are better than internal shades were found to be not always true! I did a small test using Kindow Roller blinds which simulated an office model with a South facing façade and a window-to-wall ratio of 80%. In order to compare and benchmark the performance of Kindow Roller blinds, the following case studies were considered.

- Case 1: External roller shades with non-reflective material properties.
- Case 2: External roller shades with reflective material properties.
- Case 3: Internal roller blinds with non-reflective material properties.

- Case 4: Internal roller blinds with reflective material properties.
- Case 5: Internal roller blinds with the Kindow control strategy.

Cases 1 to 4 are the baseline cases which are chosen in such a way to represent the performance of conventional automated shading systems available in the market. Case 5 uses the same reflective shade material as case 1 and 3, but with the advanced Kindow control algorithm. A careful combination of shade materials with reflective properties and the Kindow control strategy can lead to 6.5% energy savings compared to external shading systems. Figure 3 shows the results of the study.

3. *Final Database for Client consultation:* In order to solve the third problem for Kindow a client database is being created where various cases with varying input parameters such as Glazing properties, shade material properties, lighting, heating and cooling efficiencies, etc. are being simulated under varying scenarios of Window-to-Wall Ratio, location and orientation. These simulation results will help Kindow to easily estimate its operational performance when a client comes in with its project specific requirements and suggest the optimal combination of glazing and shading properties allowing for better client consultations. ■

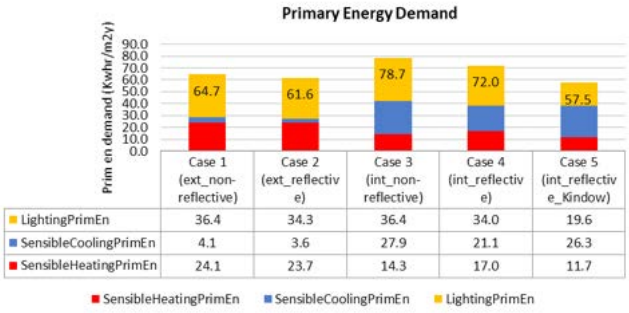

Figure 3. Primary Energy Demand comparison

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- Mechanical Engineering (ME)
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- Industrial Engineering & Innovation Sciences(IE&IS)

The program consists of two main parts. PDEng trainees work on their design project in collaboration with a company or as a part of a bigger (inter)national project and parallel to that they are taking part in different courses provided by TU/e (4TU's). These courses help them to improve their design skills, professional skills (communication, teamwork, management, entrepreneurship), and their disciplinary knowledge related to their project and their background to deepen and broaden their knowledge.

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'We leverage the full extent of our knowledge in support of a healthy and sustainable world'

This is the Valstar Simonis mission: we recognize the necessity to make our society sustainable. We are an independent engineering agency, established in 1948, with a proven track record of providing integrated design solutions for all living building systems.

Our enthusiastic team of consultants and engineers delivers custom solutions for all services in the field of comfort, energy, sustainability and safety in and around buildings. We stimulate integrated design (by using BIM) and sustainable solutions (by using BREEAM and WELL).

We work on a wide range of projects across multiple markets, ranging from renovation and new developments to repurposing of entire buildings in markets including healthcare, education, performance venues, commercial, research, higher education,, offices, and datacenters.

In this article we put one of our recent projects in the spotlight; it concerns an ultramodern office building with an important leading actor; the user itself. ■

Impressive entrance with huge LED screen
© Barwerd van der Plas

An entrance hall with a 50 square meter LED screen, a fitness room with a sauna and hammam, an elevator with LED screens, a roof terrace with a view over the IJ waterways and the latest innovations such as facial recognition and sensor technology. Flow Houthavens in Amsterdam is an ultra-modern building, where users are surprised and get into 'a flow'. "It will be a building where the user is always put first, where people should really feel happy and which is also very sustainable. It is great to be able to work on such a project", says Theo de Boer, director of Valstar Simonis.

The Flow ® is an initiative of the architect firm MVSA Architects and project developer ToBeDeveloped. For these initiators, Flow Houthavens is a "proof of concept". If it turns out to be a success, they will roll out the concept further to existing and new buildings in and outside the Netherlands.

Theo: "The special thing about The Flow® is that there is really an idea behind it. It is not only a very sustainable building with a BREEAM Excellent certification, but also a building where everything revolves around the user's well-being. The Flow® is the first new-build project to be awarded a WELL Core v2 Platinum certificate. Where BREEAM looks at the impact of a building on the environment, WELL looks at the health of the users."

WELL BUILDING STANDARD

The WELL Building Standard provides guidelines for seven categories: air, water, nutrition, light, fitness, comfort and mind. Theo explains: "For example, in The Flow®'s company restaurant, mainly healthy and fresh food is served, there are sufficient water taps in the building, a lot of attention is paid to acoustics and the lift is 'hidden' to stimulate the use of stairs. The technical installations recognize you when you enter a workspace and then automatically the lighting and temperature will be adjusted to your preferences. This lighting also takes your biological clock into account, so that users will feel much more comfortable."

LESS ABSENTEEISM THROUGH BETTER HEALTH

In order to comply with the WELL guidelines, substantial investments had to be made. An investment that pays for itself many times over, according to Theo. "The housing costs of a company often amount to about 2 to 3% and the wage costs up to 60 or 70%. A healthy working environment ensures higher productivity and less absence and is therefore an interesting investment in that working environment.

And on top of that: it is becoming increasingly difficult to retain good people. A sustainable, healthy and pleasant working environment can make the difference.

HIGH AMBITIONS

From the start Valstar Simonis was closely involved in the prestigious project in Amsterdam's Houthavens. "A great collaboration", describes Theo. "The client is very ambitious and it is a great challenge to go along with that. We have a lot of knowledge about the latest innovations and are happy to show what is possible."

TECHNICAL INSTALLATIONS AND FLEXIBILITY

The Flow® is designed with flexibility in mind. Each space can be configured in several different ways. Workplaces can be positioned in various layouts. Elevators, staircases and toilets are core communal elements. Shared areas in the lobby and on the top floor provide additional options for entertaining guests and organizing special events.

The flexibility is also reflected in the installations. The installations are easy to adapt to the new spaces that are created. The layout is easy to program in the operating and smart building system. Lighting in The Flow® not only works on the daily rhythm but also on the conditions outside.

The light supply in The Flow® ensures a healthy biological rhythm and is based on anti-glare technologies, excellent color quality and abundant daylight. All this can be operated and monitored via an application linked to the smart building system. In addition, this application can also be used to regulate the climate and it contains information about the air quality, including CO2 content, air pressure, air humidity and volatile organic compounds (VOCs). There are also functions for reserving spaces, cars and group lessons in the fitness room.

The building has the highest insulation standards, including triple glazing. In addition, the building has an Aquifer Thermal Energy Storage (ATES) installation, which stores and recovers thermal energy in the subsurface and provides The Flow® with cooling and heating in a combination with heatpumps.

The Flow® Houthavens, a state-of-the-art office building. © Patrick Coerse

The 'catering concept' focuses on reducing CO2 emissions, working with seasonal and local products as much as possible and reducing inorganic waste, such as plastic and disposables.
Under the building there is a small parking garage with a limited number of places for normal cars. A relatively large number of places (approx. 30%) are reserved for electric cars. In addition, the use of bicycles is encouraged and shared bicycles are made available to go to appointments.

CIRCULAR MATERIALS

The overall design takes into account the use of recyclable materials. For example, the ceiling is partly made of alusion, a unique material made of recycled aluminum with a high acoustic effect. In the context of circularity and the creation of unity, this material has also been used in the bar on the top floor, elevator and toilets, for example.

Furthermore, the construction is made up of a steel construction (steel columns and beams) with prefab hollow core slab floors in between, which can be easily dismantled. The curtain wall, the glass fronts and the aluminum floor fins can also be easily disassembled and therefore reused.

"FUTURE PROOF"

The office of the future will increasingly require rapid adaptation to social, technological and organisational changes. The current changes due to COVID-19 clearly illustrate just one way in which unexpected adaptations are required. The Flow was designed from the ground up to be flexible. As a result, changes to the layouts of office spaces can easily accommodate new social distancing guidelines. And because the underlying technological infra-structure (mechanical, electrical) was incorporated in the flexible design, the new layouts can be implemented without extensive renovations.

The Flow® Houthavens opened its doors in January of this year and can rightly be called The New Order in High Performance Buildings.

Want more information about this project or an internship at Valstar Simonis? Please visit our website: www.valstar-simonis.nl ■

The office layouts can be easily adjusted and technical installations recognize you when you enter an office and adjust lights and temperature to your preferences. © Barwerd van der Plas

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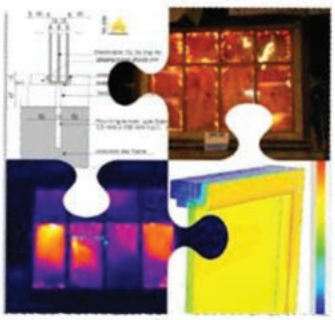
FELLOW/fse Stichting Fellowship FSE WO² Eindhoven University of Technology

The business network for education and research

Engineering Fire Safety





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Bachelor End Project on Thermal Bridges

Author
L. (Laurens) Castenmiller (BSc)

Before you can start your building physics and services (BPS) master you need to complete the pre-master or finish your bachelor. In this article, I will share my experiences during my bachelor end project (BEP).

My BEP is focused on retrofitting a dwelling in a way that it meets the stricter sustainability requirements of today. The attention is focused on two dwellings which are located in the north-east of Eindhoven in the neighborhood 'Oude gracht oost' built in 1962 but have some shortcomings in various aspects concerning building physics. Since they do not meet the current sustainability requirements, the comfort of the residents is compromised.

START OF THE BEP

We started the project in groups of three where a site visit was planned along with meeting the residents of the dwellings. The existing conditions of the dwellings are documented. The color of the reflection of a flame, for example, gives information about the window, whether it is a double glass construction or HR++. At the end of the visit, the residents gave us a good cup of coffee and questions could be asked. After this meeting, we decided that each group will focus on a specific BPS related topic for the coming three weeks. The topic of heat and thermal bridges was appointed to me. At the BPS lab, which was already quite familiar for me, an infrared camera was borrowed. This is quite an expensive camera, however, the staff of the BPS lab were friendly and did help us by providing information about the camera. In high school, I did work on a project in cooperation with Schöck Nederland B.V. so I already was familiar with this type of camera. It is possible to capture infrared imagery using this instrument/camera. The infrared image provides the color and the amount of heat which is captured in each individual element. With the help of those images, weak links in the dwelling can easily be spot.

On the outside, the weak spots do have a high temperature (bright color) in comparison with the other areas. The IR imagery is ideally captured without interference of solar radiation to prevent the thermal mass from heating up and affecting the results. After this analysis, we decided to focus on a specific BPS related topic for the rest of this project in groups of two students.

ONE BPS RELATED TOPIC

The topics are Materials, Energy, Heat, and Drawings. Each topic has a different supervisor which is more involved in the specific topic. I am interested in the topic lighting, however, this topic was not on the list. It was not possible to add this topic, so I decided to continue working on the topic of heat. The supervisor for this topic was Henk Schellen and I, together with Tobias Quene, worked with the software program COMSOL multiphysics, made some proposals, and did some condensation calculations for these proposals.

The IR imagery is analyzed, and some typical spots which acted as thermal bridges were identified. I did specifically focus on the balcony floor, a temperature gradient can be noted (Figure 1). Close to the facade the temperature is the highest (bright color), which indicates heat losses from the inside to the outside, while the temperature at the edge of the balcony is lower (dark color). All spots, of this research, are also valid for the other dwellings under consideration, which makes the proposed design solutions also applicable for these cases.

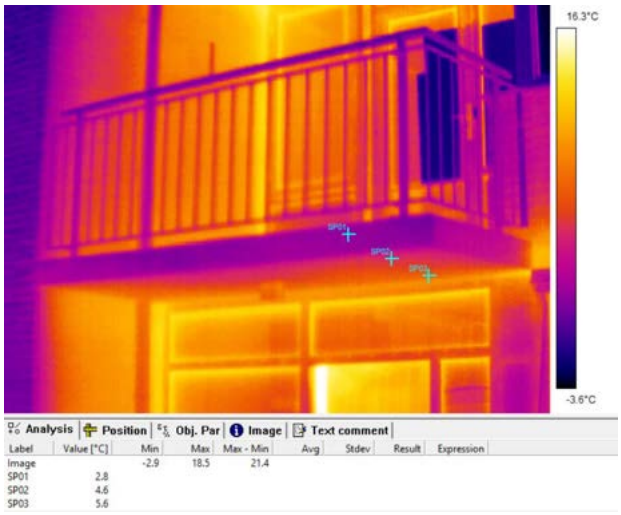

Figure 1. Infrared image of the balcony

SIMULATIONS

In the software program COMSOL multiphysics, these identified thermal bridges are detailed before the proposals could be simulated. COMSOL multiphysics is a mathematical simulation program that covers fluid dynamics and thermal behavior of materials and structures. For our research 1-D heat transfer in a construction is calculated. We both were not familiar with COMSOL multiphysics, so we gained knowledge by making use of provided tutorials of the software program. After completing these tutorials we could start creating a model of the balcony, and assign the material properties of each individual part. The material properties are necessary because different materials have different values of thermal conductivity, and act differently with respect to heat transfer. The material properties can be adjusted manually, but these properties are mainly picked from the COMSOL library to achieve more consistent results. Once all the constructions are specified, the simulation of the models could start, and a thermograph of the balcony is created (figure 2). The color of each area represents a temperature that should look like the colors in figure 1. However, there is a large difference in perceived color and temperature values. This means that there is a flaw in the temperature color and value scale. This latter can be ignored because this difference is of the same magnitude in all models.

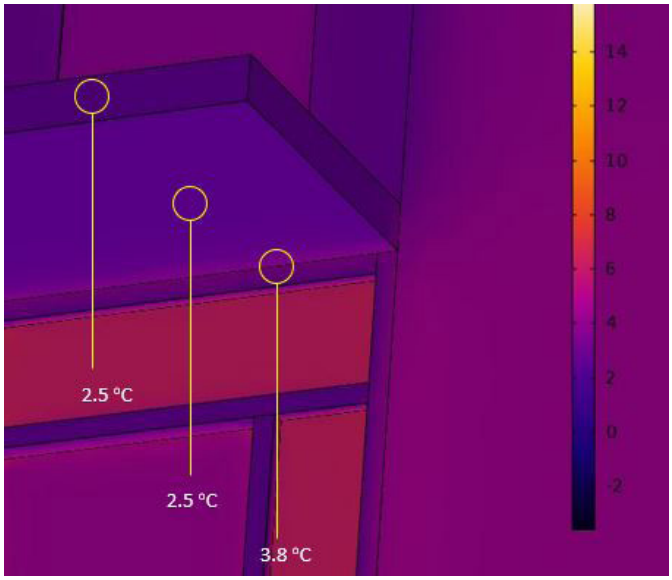

Figure 2. COMSOL model of the balcony

3 PROPOSALS

The heat loss of the analyzed construction is calculated via the inward heat Flux, which does represent how much heat is entering the structure. For the balcony, this calculated inward heat Flux is -228.61W. This value is negative, which indicates that there is heat escaping the structure instead of entering the structure. This effect results in higher energy bills and less comfort which should be prevented, so 3 proposals are created, which are:

- Using a thermal break
- Using thermal insulation on the external surface
- Using thermal insulation at the ceiling (inside of the dwelling)

Since proposal one and three do not prevent heat loss in both directions (horizontal and vertical), a combination of both proposals are made. However using a thermal break requires supporting the structure to prevent the collapse of the structure, so this adjustment will not be used as a final proposal. The second proposal does prevent heat loss in both directions, however, lots of insulation material is needed which has a significant financial investment. So this proposal is adjusted into a partly wrapped balcony according to a rule of thumb which says that heat loss is prevented if a slab is insulated for 1 meter in the horizontal direction. A resistance of at least 1 meter of concrete will prevent heat loss. All proposals are simulated, and the simulation of proposal two shows an inward heat flux of -16.792W instead of -228.61W.

CONDENSATION CALCULATIONS

The possible occurrence of internal condensation is analyzed by making condensation calculations to know if sufficient levels of comfort are achieved. The temperature ratio (TR) is used, and should, according to regulations for residential buildings, be higher than 0.65. If there is a large temperature difference at the surface area, the TR is lower than 0.65 and if there is almost no difference the TR is higher than 0.65. The higher this ratio, the more comfortable the inhabitants feel. A TR of 0.79 can be inferred based on figure 3.

The occurrence of internal condensation is calculated with the help of a Glaser graph (figure 4). The water vapor saturation pressure (red line) does not intersect the actual water vapor pressure in the structure (green line) so no internal condensation occurs. In other proposals, internal condensation occurs which is solved by using a different insulation material or by applying a vapor barrier. These hand calculations are also done with help of the software program COMSOL and don't show many differences which means that the hand calculations are reliable.

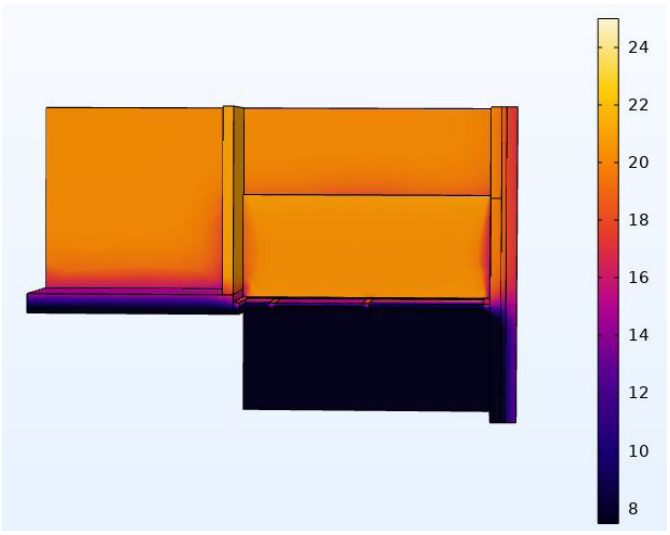

Figure 3. Temperature ratio of the final proposal

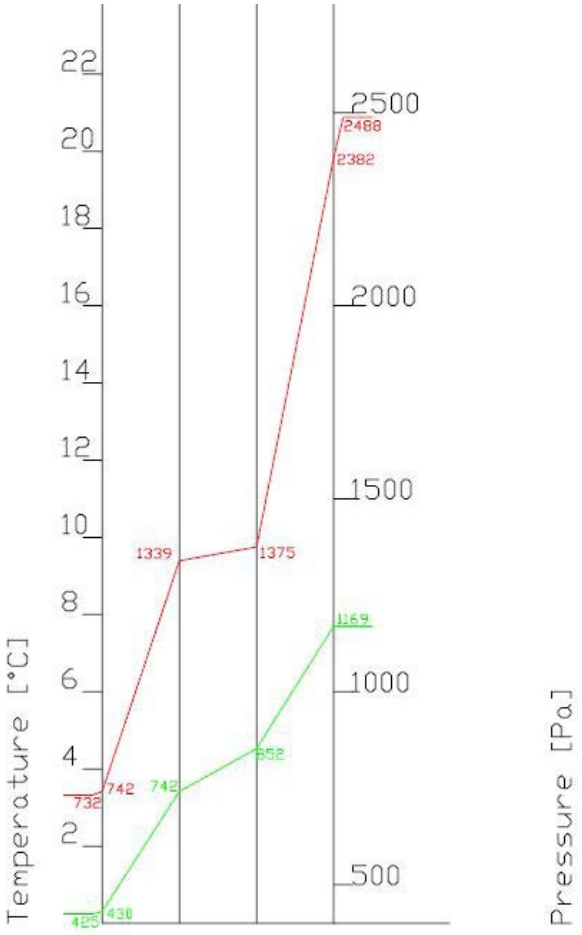

Figure 4. Condensation calculations (Glaser graph)

CONCLUSION

There are some possible improvements after finishing the BEP. The reduced inward heat flux of each proposal is calculated by assuming the inward heat flux of the actual situation is zero, however, the structure always loses some heat towards the outside, which means the inward heat flux is always negative, which results in a positive impact on the temperature loss in all the proposals.

Besides some struggles at the beginning of our BEP with the group formation and the use of some unknown devices and software programs, the BEP was very useful to conclude the bachelor, I learned many (new) things, which are useful in the master. I passed my BEP in time for the summer break, where I took a few weeks off before starting with my master Building Physics and Services! ■

Silver Lining

5th Lustrum

SVBPS MOLLIER

1996 - 2021

Dear reader,

This year Mollier is celebrating it's 25th birthday which means it's our 5th lustrum. However the world seems to turn a bit different this year. Nevertheless the committee is still busy to make sure everything will fall into place. For all activities different scenarios are worked out. This way we make sure they can take place. That may be in a different form, depending on the situation. We hope to see you there!

Yours sincerely,

The 5th lustrum committee

SAVE THE DATE!

Opening Lustrum year
4th of February 2021
Café Thomas, Eindhoven

Symposium
16th of March 2021
Blauwe Zaal, TU/e

Lustrum Gala
5th of June 2021
Location t.b.a.

From left to right: Nora Kuiper, Jesper Priester, Maud Staassen and Brent Wiebes

A Digital Test Environment for Advanced Building Skins

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Prof. dr. ir. J.L.M. Hensen
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INTRODUCTION

Within buildings, energy is required to maintain a comfortable and healthy indoor environment. On earth we receive an astonishing amount of energy from our sun and this solar energy can be harvested by PV-panels for electricity, or by sun collectors for thermal energy. However, the solar radiation can also be directly utilized within a building, to reduce the energy demand and increase of the levels of comfort. However, this utilization can also cause the opposite effect, which depends on the ambient conditions and the building demands. In terms of daylight, high utilization is desired due to the positive influence on the well-being of its users [1]. Direct advantages are savings in electricity consumption for lighting and the positive impact on the productivity of office workers. Nevertheless, large fenestration areas can also increase the risk of discomfort by glare, resulting in the opposite effect [2].

Multi-state facades have regularly been identified as a promising development trend [3] and are capable of adjusting their properties regarding solar admission into multiple states. This can, for example, refer to shading devices that can be deployed in multiple positions or the use of various shading fabrics with different optical properties. However, the control strategy of these multi-state facades can be challenging due to conflicting objectives (e.g. providing view vs. preventing glare) and dynamic influences of the environment. There is a growing interest for advanced controllers within the built environment and especially the model-based control (MBC) approaches. The potential of these MBC strategies is already acknowledged in other sectors, but also in several building applications, such as Building Management Systems [4].

The Dutch Organisation for Applied Scientific Research (TNO) is currently developing a multi-state facade along with model-based control (MBC) strategies. These research and development (R&D) activities are carried out in cooperation with the solar shading supplier Verosol and the façade construction company Scheldebouw. Within the graduation project, a crucial aspect for the R&D process has been developed, a time-efficient and accessible test environment.

MULTI-STATE FACADE WITH MPC

The main function of conventional dynamic shading devices is limiting solar admission in order to prevent glare and/or cooling demand. Shading screens with a reflective coating can be very effective in reducing cooling load or preventing overheating in warm periods [5]. However, these solar gains are not always unwanted; during certain parts of the year, it could also be used to reduce the heating demand. With the application of an absorptive screen at the right position, glare can be prevented but the near-infrared part of the solar radiation can be utilized within the building. The demand for solar radiation in the visual and thermal spectrum depends on the ambient conditions and building demands. Through the combination of both screen types with variable shading heights, the system provides more possibilities to meet the desired solar admission in each situation. The first concept of this multi-state façade consists of three single glazed panels, creating a double cavity. A reflective shading screen will be located in the outer cavity, and an absorptive shading screen in the inner cavity, see Figure 1. By locating the screens within non-ventilated cavities, the exposure to external influences is limited. There are countless numbers of variations possible within multi-state façades and these must be evaluated in a later process of this R&D process.

An MBC strategy is being developed for the dynamic screens within the double-cavity façade (DCF) system. Figure 1 also shows the global operation of the MBC with the corresponding inputs and outputs. Within an MBC, a simplified building model is implemented to exploit predictions of the possible future responses of a system (in our case a building) as a function of different screen positions of the DCF, so-called control sequences. The inputs of the model are the current status of the building, future

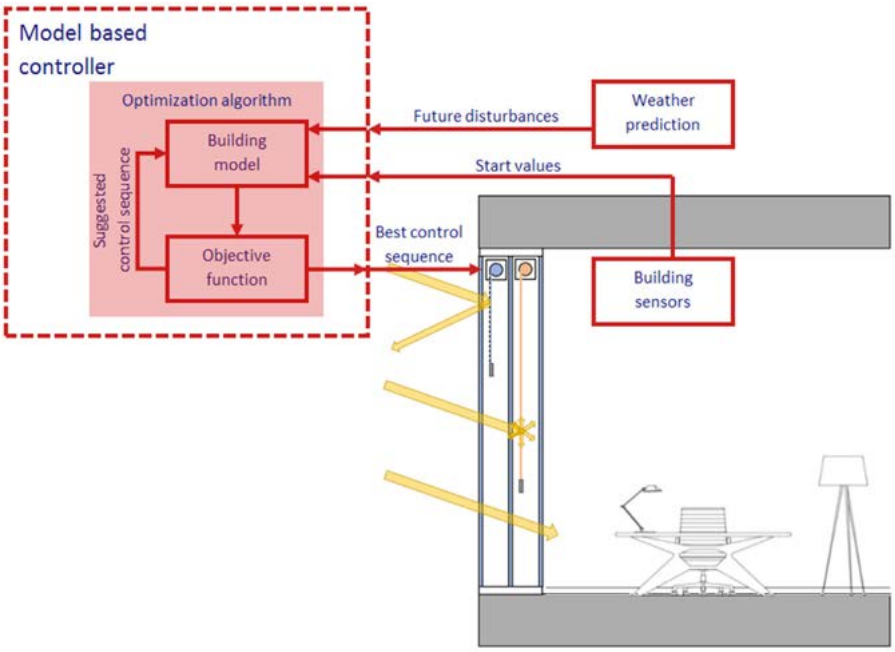

Figure 1. The double cavity façade with the operation of the MBC

disturbances by a weather prediction and a suggested control sequence for the façade system. The building model creates multiple predictions based onthese inputs and the MPC uses it to select the best control sequence, according to an objective function. The best control sequence is selected according a pre-defined performance index and eventually implemented within the DCF.

TEST ENVIRONMENT

For the development and deployment of an advanced controller, like the model-based control (MBC), a test environment is required to obtain insight in the complex dynamic interaction within the building and the impact on comfort and energy use. Disadvantages of physical test environments (e.g. time-consuming, labour intense, financial consequences) can form a significant barrier for the development of a MBC.

Nowadays, building performance simulations (BPS) are an established tool for supporting the design and operation of high-performance building [6]. These tools are predominantly applied in the detailed and early design studies because of the complete controllable test conditions and the detailed insight into the dynamics within a physical system. This complete overview/insight is ideal within a test environment for the development of an MBC.

Figure 2 shows the framework of the developed test environment. At the centre of this environment is the BPS tool EnergyPlus. This validated tool enables the performance evaluation regarding HVAC systems, energy consumption and thermal comfort within a building [7]. An extension of this tool is LBNL Window 7.7, which increases the simulation possibilities regarding multi-state facades. EnergyPlus enables the simulation of daylight, but this method showed significant shortcomings in the simulations [8]. A good alternative was the BPS tool Radiance, which is a commonly used and validated tool that uses the reverse raytracing method [9].

A bottleneck within the existing simulation tools, is that there are no standard tools that allow interconnection with external advanced controllers and this is essential for the interaction with the MBC. This bottleneck is tackled by a so-called middleware, Building Controls Virtual Test Bed (BCVTB). This tool is used to establish a data exchange between the different tools and controller at each simulation time step, creating a so-called co-simulation. The software tool Matlab is eventually used to distribute the data within the co-simulation, but also for the interaction with the external advanced controller.

The developed MBC will in practice be installed on a server and invoked by a network connection, creating a hardware-

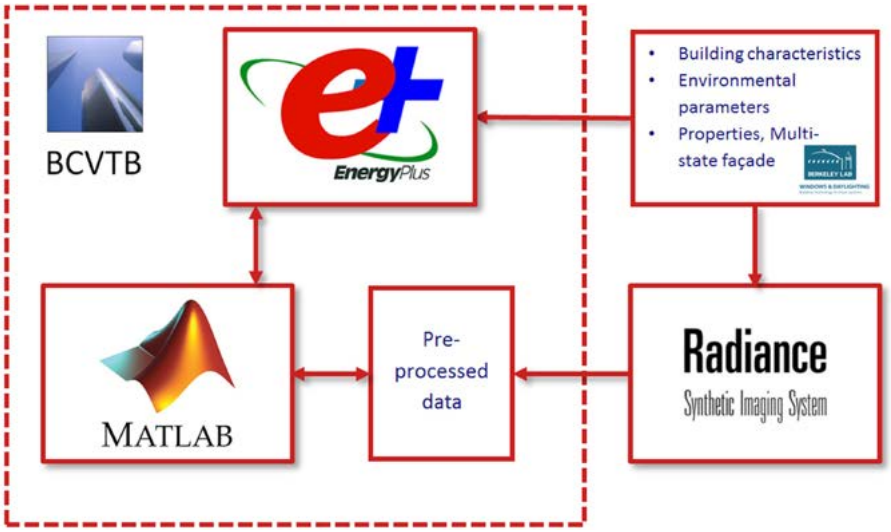

Figure 2. Framework digital test environment

in-the-loop simulation. The network connections is established with a REST (Representational state transfer) API (application programming interface) and the test environment invokes with this connection the MBC, which responds with a control sequence based in the sent data of the test environment. With the establishment of this connection the bottleneck of existing simulation tools, the interconnection with external advanced controllers, is tackled. This eventually opened the door for a wide variety of analyses. This also allowed for the performance evaluation of the first prototype of the MBC in combination with the DCF. The development of the test environment expanded of the complete graduation period with multiple verification and validation studies, which can be consulted in the thesis.

APPLICATION OF THE TEST ENVIRONMENT

An essential function of the test environment was to support the development of the simplified building models inside the MBC. This model is essential for the performance and operation of the controller. The complex physical dynamics within a building must be captured within a model. This requires a detailed insight into these physical dynamics, which can be provided by the test environment. The development of this model also consists of the selection of accessible and feasible inputs with possible associated models and the desired prediction horizon. In the case of the TNO project, the use of a resistance-capacitance model (RC-model) is intended. This model requires an extensive amount of data, the inputs for the model, to estimate the thermal resistances and capacities.

Other applications during the graduation period are the development and evaluation of an advanced rule-based control (RBC) strategy, a study to the configuration of the DCF and the evaluation of the MBC operation. However, this is just a fraction of the possibilities of this digital test environment. In a subsequent phase of the R&D, the test environment can be deployed to analyse and improve:

- Robustness of the controller
- The objective function and corresponding performance index
- Response on inaccurate future disturbances (e.g. weather prediction)
- Interaction between controller and façade system
- The multi-state façade design (e.g. alternative materials)
- Performances (energy use, comfort)

BPS tools can be adjusted to the specific test conditions of these analyses. It also simulates the dynamic interaction between the MBC and the building which is essential for the operation/ performance of an MBC. In addition to these applications, the developed test environment is widely usable for alternative studies within the R&D process (e.g. other climates, building types, façade designs). This test environment will significantly support a faster development and eventually better performing advanced building skins and MBC's.

PERFORMANCE EVALUATION

The support and capabilities of the test environment are demonstrated by different use cases with the advanced building skin proposed by TNO, in particular. In this article, the focus is on the comparison of control strategies in combination with the DCF. A reference office defined by the International Energy Agency (IEA) was the base of the use case studies [10]. This is a three-person single zone office space (4.5 x 8.0 x 3.0 [m]) with some slight adaptations for this specific project. This reference office is part of a larger complex; this is represented in the simulation environment by defining all surfaces as adiabatic except for the south-oriented wall. This wall is a fully glazed façade with the application of the DCF. The location and climate of the reference building are based on the climate conditions of Amsterdam. The first prototype of the MBC had its limitations and a complete

focus on preventing thermal energy demand. So visual aspects and the corresponding effect on the energy demand of the lighting system are not taken into consideration. The annual performance of this controller is shown in Figure 5.

To put the performance of the MBC in perspective two other control strategies are also evaluated with exactly the same test conditions, operating the DCF system. The first variant, presented in Figure 3, has none of the screens activated. The control strategy in the second variant is based on the IEA reference office, see Figure 4. In this strategy, the reflective screen is activated when the total solar radiation incident on the external façade (vertical plane) exceeds a threshold of 120 [W/m²][10].

The performance indicators of these use cases are the total heating and cooling demand net delivered to the room and the total energy demand for artificial lighting. For visual comfort, two performance indicators are applied, the Daylight Glare Probability simplified (DGPs) and the Spatial Daylight Autonomy (sDA). DGPs indicates if glare discomfort occurs through daylight while the sDA indicates to what extent a surface receives adequate daylight. The performance evaluations provided insights into the performance of different façade systems and control strategies by the conducted use cases. The need for these facades and control strategies are confirmed by the use cases.

The following findings deserve further attention:

- The need for dynamic shading devices are confirmed by results of figure 28. The cooling demand is circa 125% higher as a standardized office [10] and the users perceive glare in circa 80% of the occupied time.
- •These results also indicated the interconnection and conflict between the performance indicators. The prevention of solar gains by the activation of the reflective screen, has a positive impact on the cooling demand and the occurrence of glare. However, the impact on the heating demand, sDA and energy demand of the lighting system.
- The total annual cooling demand of the RBC and MBC are almost the same, the difference is 0.17 [kWh/m²]. however, the total annual heating demand of the RBC and MBC are not alike and this demand is 133% higher in the MBC compared to the RBC. The variant with no shading has maximum exploitation of the solar thermal energy.

The detailed insight of the annual results are presented by a heat map in Figure 6. Within the 24th week, the screen is activated from 5am, when no occupants were present or cooling was activated. This could indicate that the controller takes dynamic effects of the indoor environment and climate into consideration, to prevent a peak in the cooling demand in the future. The limitations of the MBC and a complete focus on preventing thermal energy demand is also visible in this figure. The visual aspects and the corresponding effect on the energy demand of the lighting system are not yet taken into consideration. There is no pursuit of a balance between these performance indicators. More uses cases are evaluated in the thesis, with more detailed results and conclusions.

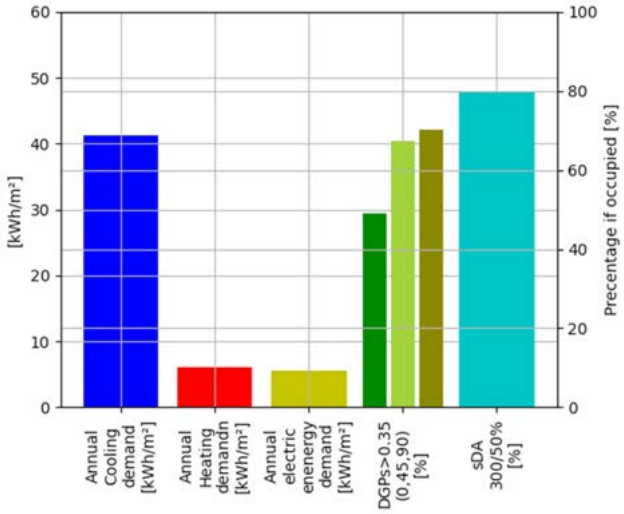

Figure 3. Annual overview results: DCF with on shading activated

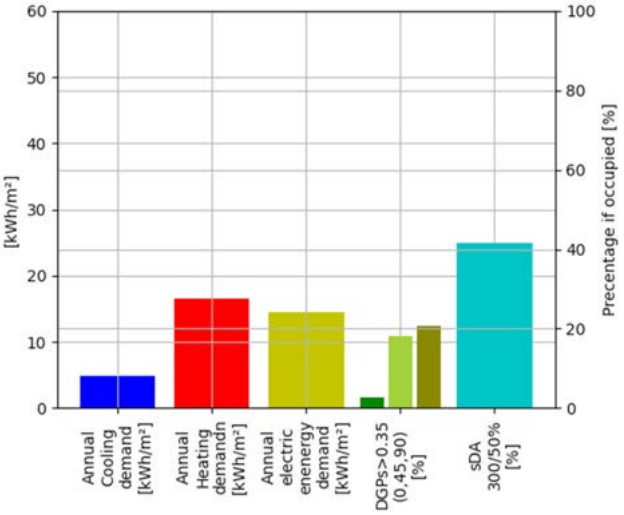

Figure 4. Annual overview results: DCF with standardized RBC

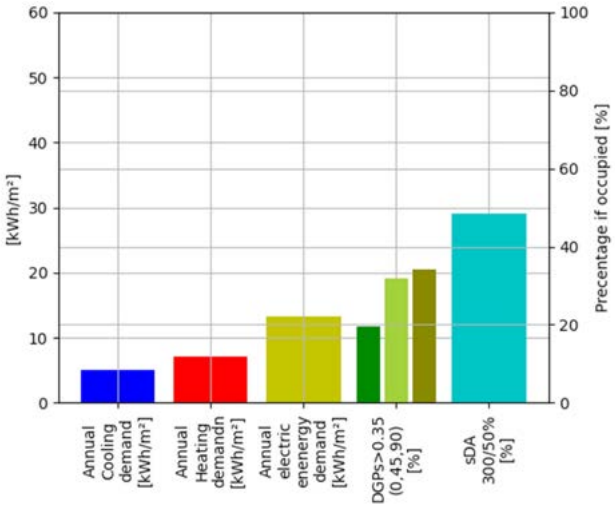

Figure 5. Annual overview results: DCF model-based controller (MBC)

CONCLUSION

The support and capabilities of the test environment are demonstrated by the different use cases with the TNO project in particular. The test environment is developed for projects like the TNO project, making it a most fitting demonstration. The test environment provided essential support in the development of the building model within the MBC. The detailed insight into the physical behaviour enabled different

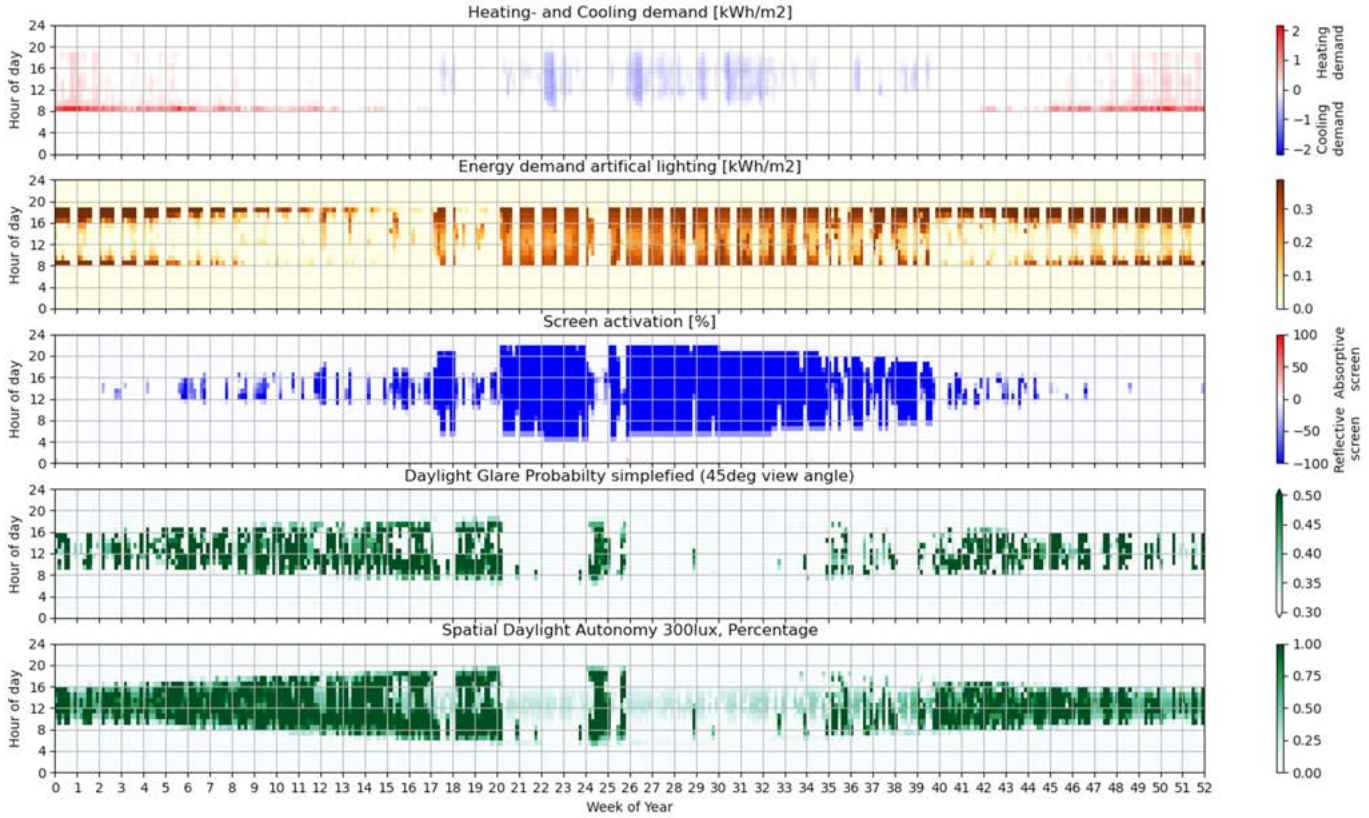

Figure 6. Detailed overview annual results, DCF with model-based controller (MBC)

kinds of parameters which were impossible to monitor in a physical test set up within the time and financial scope of this use case. A physical test setup, would require seasonal around-the-clock experiments which are labour intensive and time-consuming. Various intended applications are suggested within the further R&D process where the test environment can provide essential support. These intended applications require a test environment due to the required dynamic interaction between the MBC and the building. However, this requires the interaction of the test environment with an external advanced controller. This requirement is demonstrated by a network connection to a real external advanced controller. This also allowed the performance evaluation of the first prototype of the MBC with DCF.

The performance evaluations provided insights into the performance of different façade systems and control strategies by the conducted use cases. The need for these facades and control strategies are confirmed by the use cases. This is similar to the clear interconnection between the conflicting objectives and the challenge regarding control strategies. The first MBC prototype showed despite its limitations, the ability to take into consideration the dynamic effect of a building. This controller had a specific focus on preventing a thermal energy demand and had a quite optimal performance regarding this subject. This could confirm the potential of the system; however, an implementation of the visual comfort is required to provide a good conclusion about the double cavity façade with a model-based controller. ■

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Onze medewerkers zijn onze belangrijkste succesfactor. Vanuit deze overtuiging bieden we een gezonde, veilige en motiverende werkomgeving waar ruimte is voor persoonlijke ontwikkeling. Ons snelgroeiende bedrijfsonderdeel installatietechniek is altijd op zoek naar jonge professionals. Inmiddels werken er al drie ex-Mollier leden in ons gezellige team. Binnen Ballast Nedam draag je niet alleen bij aan het integrale installatie-ontwerp, ook zie je van dichtbij hoe het daadwerkelijk gerealiseerd wordt!

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3D Steady RANS Simulation of Pollutant Dispersion in Streets

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Rapid deteriorating air quality and pollutant dispersion are considered to be some of the largest problems related to health in urban environments. Previous studies on pollutant dispersion, conducted by Computational Fluid Dynamics (CFD) and wind-tunnel testing, used a point or line source which represents an ideal situation without taking into account the geometry of the source. Therefore, this study investigates the feasibility of providing a more accurate approach in predicting the near-field pollutant dispersion within a street canyon by replacing the idealized source (Case 1) with a realistic car geometry (Case 2).

METHODOLOGY

The reference study of Tominaga and Stathopoulos was used to validate the near-field pollutant dispersion in a street canyon through 3D steady RANS simulations [1]. The geometry of the computational domain was built according to the reference paper in which the shape of the canyon was defined by an H/W and H/L ratio equal to 1.0 and 0.5, respectively, where H is the building height (i.e. 1.8 m), W is the distance between buildings (i.e. 1.8 m) and L is the building length (i.e. 3.6 m) [2]. The wind direction was perpendicular to the canyon and the inflow conditions were defined according to the wind-tunnel tests from the reference study [1]. Furthermore, the SIMPLE scheme algorithm for pressure-velocity coupling, the QUICK discretization scheme for momentum and concentration, and for the remaining k, ε, and energy equations the second-order discretization scheme was used.

In the first stage, in search for the best-performing computational settings, the impact of both grid resolution and turbulence models was analyzed. Three consecutive computational grids (i.e. the coarse, basic and finest) and five different turbulence models (i.e. Standard k-ε model (SKE), Renormalization Group k-ε model (RNG), Realizable k-ε model (RKE), Standard k-ω model(SKO) and Shear Stress Transport k-ω model(SST)) were compared based on turbulent kinetic energy (k) and the mean concentration ($\langle c \rangle$). The finest grid (of 509,000 hexahedral cells) combined with the RKE turbulence model provided the most reliable results compared to the reference study [1].

In the second stage, CFD simulations were performed on the same street canyon using a realistic car geometry (i.e. the DrivAer model) as a source of pollutant [3]. The characteristic length (L_M), width (W_M), and height (H_M) of the 1:4 reduced-scale DrivAer model were 1.153 m, 0.508 m, and 0.355 m, respectively. The computational domain was modified by increasing the building length L (i.e. 6.39 m) to ensure that the exhaust of the DrivAer model was placed in the middle of the street canyon. The domain was divided into two separate subdomains: the outer subdomain of 681,100 hexahedral cells and the car subdomain of 1,352,660 tetrahedral cells. The inflow conditions and other computational settings remained unchanged to CFD simulations with an ideal point source.

CONCLUSIONS

The presence of the DrivAer car model redistributes the flow pattern within the street canyon resulting in the accumulation of pollutants on the windward façade instead of the leeward façade. The dispersion of pollutants outside the canyon is much lower compared to the point source because dense pollutant regions are formed on and around the DrivAer model, while further in the canyon it becomes much diluted (Figure 1). The fact that denser regions of pollutants are formed around the DrivAer model could imply that higher concentrations remain longer inside the street canyon which indicates a lack of removal.

The results provided valuable insights into the understanding of near-field pollutant dispersion related to a realistic car geometry. However, further research is necessary to formulate a more comprehensive conclusion in terms of different wind directions and street canyon configurations. ■

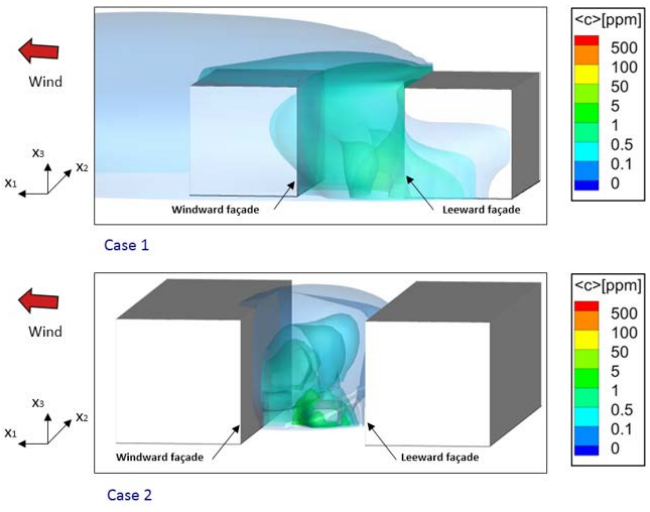

Figure 1. 3D mean concentration $\langle c \rangle$ contours: comparison between Case 1 and Case 2.

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