Computational Optimisation for Zero Energy Building Design

Interviews with Twenty Eight International Experts

by **Shady Attia**

SHC SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

International Energy Agency
Energy Conservation in Buildings and Community Systems Programme

Report Information

First edition, January 2012

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For Citation:

Attia, S., 2012. Optimisation for Zero Energy Building Design: Interviews with Twenty Eight International Experts, International Energy Agency (IEA) Task 40: Towards Net Zero Energy Buildings Subtask B.

Editing and Copyright:

International Energy Agency (IEA) Task 40: Towards Net Zero Energy Buildings

Foreword and Acknowledgments::

This work is part of the International Energy Agency (IEA) Task 40: Towards Net Zero Energy Buildings Subtask B.

The audience of this interview is building designers and building energy specialist concerned with the implementation and integration of optimization techniques for high performance buildings.

We would like to thank all those who have contributed to making this report, and we hope you enjoy reading this publication.

The author would like to thank the following organisations and individuals for their contributions for this document.

IEA SHC Task40/ECBCS Annex 52, Towards Net Zero Energy Solar Buildings:

- **Josef Ayoub, Natural Resources Canada**
- **Andreas Athienitis, Concordia University**
- **William O'Brien, Concordia University**
- **Scott Bucking, Concordia University**
- **Mohamed Hamdy, Aalto University**

Funding of this work was provided by the Université catholique de Louvain in Belgium.

Shady Attia

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Executive Summary

Given the implication of designing Net Zero Energy Buildings (NZEBs), which involves complex passive and active design strategies, the use of computational automated optimization techniques is becoming more essential. Therefore, this structured interviews aims to assess gaps, needs and problems considering the integration of optimization techniques to support the design of NZEBs. This work is part of the International Energy Agency (IEA) Task 40: Towards Net Zero Energy Buildings Subtask B.

The objective of this report is to gain an understanding of how experts currently use optimization tools, which tools they use, the major limitations they have encountered, and their vision for the future of optimization of Net Zero Energy Buildings. With this information disseminated, it is anticipated that software developers will be better informed of the needs of building design processionals.

A qualitative study design was employed, using semi-structured interviews. Optimisation experts working in academia and practice were recruited. The participants were identified from the IBPSA Conference Proceedings between 1995 and 2010. A sampling framework was developed to include experts in the study from Europe and North America. These groups represented the range of possible optimisation users, from researchers and designers considered optimisation in the design of net zero or high performance buildings. A list of potential optimisation experts was created and circulated between the IEA Task 40 Subtask members. Also every interviewed expert was asked to revise the list and add any potential candidate to be interviewed.

IEA Task 40 Interview with Scott Bucking, Concordia University, Canada

Interviewed: 26 July 2011 (s_buckiatencs.concordia.ca)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building engineering, physics
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes, it is part of my PhD thesis work. I use optimization search algorithms combined with databases, a text-file interface and a custom built building simulation file generator.
3. **How many projects or case studies have you performed?**
   Five in total, but one in great detail. We worked on the Ecotera house specifically and the goal was to design that building. Its a near zero energy solar home. What we were looking for is if we would redesign that building again what things that we can do better.
4. **Approximately, how long does each project or case study take?**
   Depending on the size, anywhere from a couple weeks to a couple months. For the Ecotera house we had to wait for measured data so had to wait long enough time to collect quite significant data to calibrate the model .
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   I have used several: GenOpt, Matlab toolkit, ParadisEO. For my research I use custom algorithms (much more flexibility). For the Ecotera house we used EnergyPlus for modelling and for optimisation I used my own stuff. It's a variant of LISP which is very good for programming artificial intelligence algorithms which optimisation algorithms fall under. The reason I did it, I want a lot of more flexibility in terms of finding ways to optimisations solutions. Because we have very various amounts of coupling in-between design parameters and that should also affect which search strategies you use for optimisation.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Python and Clojure (a LISP dialect).

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Residential mainly. Commercial studies in progress in Canadian climate.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**

5+ heating/cooling zones. For Ecotera we modelled three zones because we needed to separate southern zones from northern zones. If you assume that one zone you are over predicting your performance because you are assuming that everything is well mixed which is not the case for a passive solar house.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   All that you mentioned plus active and passive shading. In total we had 33 variable and they all range from facade design to thermal storage as in concrete slabs as well as integrated PV we work with that too so your roof angle will determine the size of your PV.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    A mix of both. The main thing that if design parameters interact loosely and if you make a modification to that or to another parameter it is not going to affect the other one. So you can design it separately from the other design parameters. So I use deterministic searches for loosely coupled parameters and then for highly coupled parameters I would use a separate search strategy. Loosely coupled parameter could be user behaviour or internal loads. So the main reason is that higher appliances loads are also have an impact on cooling loads but cooling loads wouldn't apply to appliance loads. So it forms a hierarchy where your internal gains will decide aspect of your design.

    So would it be limiting if you used only evolutionary algorithms?

    I could have done an evolutionary but what you do if you approach it from that, you assume that you know nothing about your design parameters. Because statistically you give equal weight to each design parameter which may not be the case for your building design. It is unlikely to be the case. So what I found is that if derive that information from the optimisation study you can use that to improve your search speed and resolution as well. So that is why I developed my own algorithms because I couldn't find a tool that would do that, which is part of my PhD research.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    Mostly ANN. I am not confident that this is a good approximation to make for larger problems.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Yes. This is part of my PhD research. I try to make estimates of uncertainty in my entire optimization methodology using Monte Carlo simulations.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    The main objective was net energy consumption. Possible exergy and embodied carbon for future studies.

    b) **What kind of constraints do you set for optimization?**

    Mostly constraints on design variables (set within specified intervals). I auto-size HVAC systems to ensure thermal comfort. For example if the cooling loads are not being met then I would add more HVAC system power to deal with that. So I actively constrained it but I didn't have any passive constraints so I didn't have any conditional ways of doing that.

    c) **What kind of stopping criteria do you set for optimization?**

    Set number of algorithm generations or set number of building simulations.

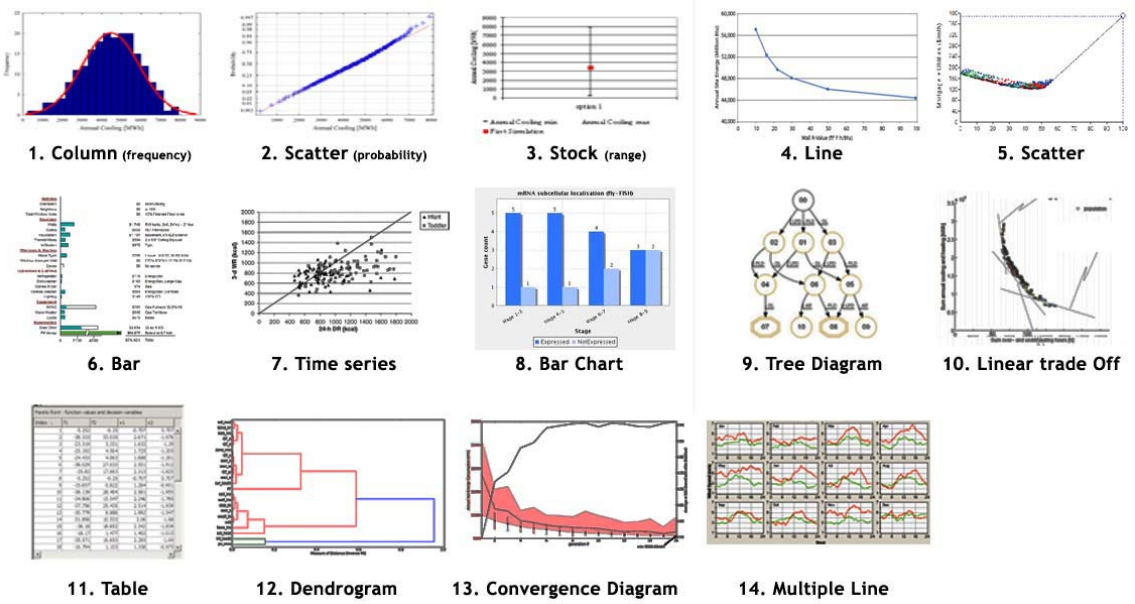
14. **How do you avoid the insolvable solutions space?**

    I find deceptive and invisible solution spaces to be less of an issue for building simulation. Optimal landscapes are flat (meaning that minor variations in design parameters do not yield large simulation differences)

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    If a simulation fails, it is due to a Fatal Error within the simulation which needs correction!

Output

16. **Do you have GUI for your own optimization tool?**
    No. I have some interfaces to aid in visualization of optimization data like D-View.
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    1, 3. Also I would look at the range of internal temperatures to give me an idea. I have many custom visualisation techniques such as number 12,13 and 14.



1 Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (Hale), 10 Linear Trade Off (Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot

Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I think optimization techniques serve as a powerful design tool. We still lack monolithic building simulation tools that would enable truly integrated optimization studies. But you can't come with a general tool for all that. I think you should come up with tools that select a much smaller scope of design problems would be a more appropriate use of these tools. So you need an interface that sets all these design variables and then you that algorithm behind it to simplify the process of finding optimal solutions. But I think you need to keep people away from the algorithm side and focus more on tradeoffs within the design parameters.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I think during early design stages and it is meant to give you idea of possible good combinations of design parameters. Early design stage would require meta-heuristics. Late design stage could use several techniques since the design space is so much smaller (I.e most of the decisions have been made)

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    Anyone interested in building design: architects, engineers, students. It shouldn't be restricted to one type of user. I think that people eventually will have enough expertise so that they don't need the tools anymore. They have their own engineering sense.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    The problem is when we talk about optimisation there is so much types of integration. There is dynamic programming there is linear programming. There is algorithms that we use more statistical based but there is so many different types of buildings such as residential, commercial, retail, hospitals and so on. So you need user interfaces to automate the creation of building simulation input files for those different building types. This is the most time consuming portion of an optimization study. Visualization techniques to show how optimization data can be used. More demonstration projects and training session such that industry can become more confident in using the above aspects.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

    Creation of monolithic building simulation platform for one to several interacting buildings in a grid (all-in-one: daylighting, control, HVAC sim, building thermal, electrical, etc); Creation of building simulation input files for all variations; User interfaces; Methods to perform quality assurance on the methodology used; optimization algorithm development (requires computer science background); visualization techniques;

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

    Sure, if it was well designed and easy to use.

24. **Which tools would you recommend?**

    BeOpt, but this is more for North America and specifically for Central America.

25. **What features would you like to find in future tools?**

    BeOpt is a trail blazer. Optimization tools still have a very long way to go! But the big feature I would like to see is teaching. I want to see people teaching us optimisation properly. I want to see it coming strongly in education. Number two is integration and really good interface developed for this. You should be able to getting people work with the right design questions, the right design variables the right design problems for your specific climate which may change wherever you are.

IEA Task 40 Interview with Remi Charron, CMHC, Canada

Interviewed: 18 May 2011 (rcharronatcmhc-schl.gc.ca)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Engineering
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Not for my current work but for my PhD work I developed an optimisation tool that coupled genetic algorithms with TRNSYS. It was actually for a single zone net zero solar energy houses. I developed our generic model in TRNSYS that had roughly 20 different parameters that could be optimised. The TRNSYS model was linked to a Fortran version of genetic algorithm program that just would go through and optimize based on different cases whether it is climate or location or size of house depending on a number of factors.
3. **How many projects or case studies have you performed?**
   Around 40.
4. **Approximately, how long does each project or case study take?**
   About one day.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? Do you use multiple tools?**
   It was a Fortran based genetic algorithm program with TRNSYS.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, the algorithm was a genetic algorithm program modified to be used for this application.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Residential in Canadian climate in various regions.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Single zone. I used type 19 single zone in TRNSYS, which was difficult to implement as few people still use this zone. I tried initially with two zones but there were more bugs and the program would take as much as 10 times longer to do two zones than the single zone. in the end I chose the single zone for speed.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   There were a number of variables including window size, overhang, building form, type of heating system, type of solar thermal system, size of solar thermal storage, roof pitch or slope, insulation type, R-value, in walls and ground slabs. PV was sized based on the energy consumption of the house. The PV was sized to meet the remaining load. The only thing that was optimised for the PV system was the slope of the roof in relation to PV output.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Evolutionary, the idea was to try to examine a number of different design options in the optimisation. I thought that would be an approach that would lead to more choices in the final design and the final solutions space. The reason to use evolutionary algorithms was because designers would select an optimal design based on how they look and the cost and by using optimisation they would have multiple solutions with their actual performance. This will give the designer more choice to choose from at the end.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Yes, I did it before, and after optimisation. Just to test how good the optimisation algorithm was in terms of parameters. Before, I would look for the optimal solutions I can come up with and then afterwards was to take the optimal design that merged and to do sensitivity analysis around the optimal solution. To see if I could come up with more optimal designs than the algorithm found.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

       It was cost based. I tried to do the monthly cost associated with the upgrade cost, energy costs, and income from energy generation. The upgrade cost was modelled like a mortgage type so there is the financing aspect into it.

    b) **What kind of constraints do you set for optimization?**

       There were to constraints thermal comfort and the roof size. Because the resulting PV system was sized to achieve a preset annual net-energy target, there was a constraint whether or not the PV area would fit on the building roof.

    c) **What kind of stopping criteria do you set for optimization?**

       The number of generations of optimisation.

14. **How do you avoid the insolvable solutions space?**

    I did every optimisation three times so check how repeatable the solution was . Mostly we came up with similar solutions in a similar amount of time,18 hours per case approximately. Then I would do that three times just for verification purposes. I tried to use discrete options in terms of the different parameters. There was no insolvable solution for the discrete options.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    It took me a couple of months to debug the simulations to make sure there is no failed simulation runs, because with the TRNSYS I found it difficult in the way it was setup, so when there were failures they would generally crash the program.

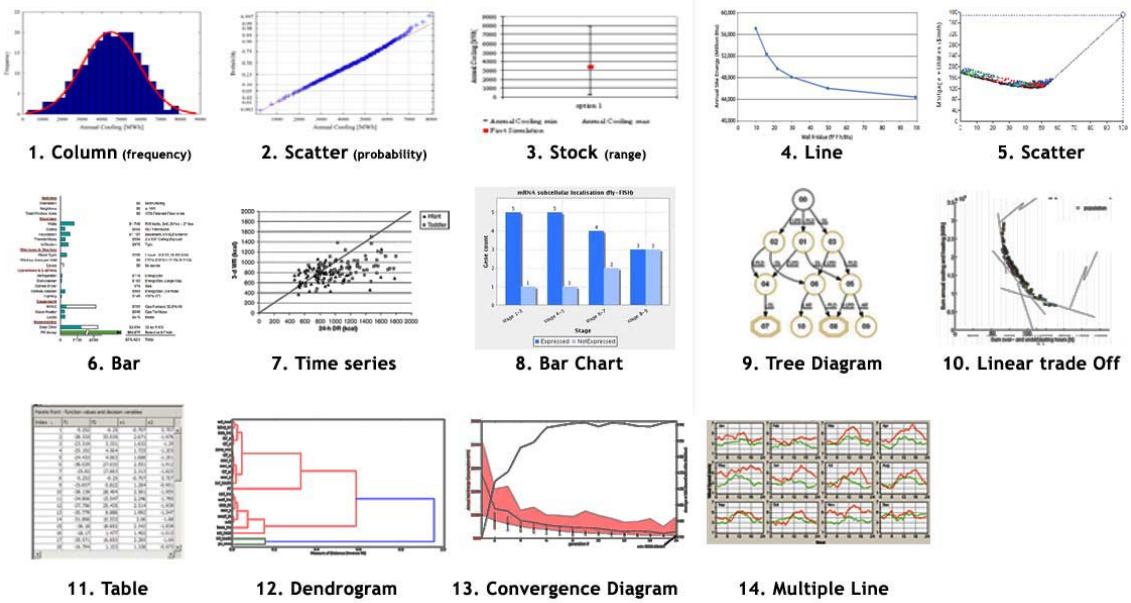
Output

16. **Do you have GUI for your own optimization tool?**

No.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

More like a scatter 5. I would see in the solutions space how the solutions are evolving, not looking at a specific design.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

Given that it takes a fairly long time to run the simulation I think it would be good that once you have an idea you would like to design you can run various optimisation simulation runs for different cases of the building and then use the output of that as a starting point with the design team so you are not starting from scratch.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

For me I developed my tools as an early stage design tool and therefore I focused on the single zone or the parameter I try to optimise more. That would help to establish or keep you on track early on in the design stage so I think for the model I developed it would be more for early design stages.

In the beginning of the design ,if you have integrated design charettes to develop the building concept, normally the first half of that process is to come with different alternative evaluating them as you if you have those solutions already modelled and optimised through an optimisation tool. Then you start the design process ahead from where you are if you started from scratch. So optimisation can do that for you. So it is better to start to use it in the early design stages till the end of the project.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

You could an optimisation tool for the different users groups if you examine more the architectural terms of the building. But it could be also for each group depending on what parameters were being optimised in the tool. The tool I developed was for residential buildings and the simulation consultant is expected to begin the design process with it. Then based on the results you can feed the results to the engineers, architects and other designers.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    As I said before it could be integrated in the decision making by helping in establishing initial design solutions or options that you start with during early design stages. So you start with more optimal cases to begin with and you would be tweaking or refining the design versus coming up with a completely different design option. So it helps in refining early on in the design process.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - There few people who have expertise with optimisation
    - It is hard to get cost data and run it in optimisation so it is difficult to estimate cost for all different options
    - Technical in terms of developing tools you confront many bugs and programming issues so you need programs that are debugged and tested
    - The run time itself is long to be used interactively in the design process
    - The accuracy of the simulation models used by the industry is not sufficient
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

    Yes.
24. **Which tools would you recommend?**

    As a starting point I recommend to check BeOpt to use and test different component.
25. **What features would you like to find in future tools?**
    - More interaction with the designer as it progresses and evolves
    - Present interactive options on the level what the designer would prefer
    - Quick almost instantaneous
    - Automated
    - Seamless transition between different design stages

IEA Task 40 Interview with Ruchi Choudhary, University of Cambridge, UK

Interviewed: 03 June 2011 (r.choudharyateng.cam.ac.uk)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   I work on energy simulation of buildings.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   I do. Numerical optimisation becomes a useful approach for problems that have specific objectives, or when trying to meet certain targets then. Optimisation as a numerical framework is a way by which we can begin to understand what parameters help us get to the targets. In my research, I apply numerical optimization to meet energy targets or performance targets appropriate for buildings.
3. **How many projects or case studies have you performed?**
   -Layout Design Optimization: a project where we explored how to solve mixed-discrete problems; with parameters that are categorical such as typological parameters in buildings versus parameters that are continuous in nature. Within the same project we investigated techniques that search global optima versus local optima.
   - Energy and Comfort Optimization: problems that requires heavy simulations. In such cases, you have to also be stingy about the number of runs that you want to do.
   - Hierarchical Optimization of Building Performance Targets: system level problems can be decomposed into sub problems that have their own individual targets.
   -Optimization for design and operation of net zero energy house
4. **Approximately, how long does each project or case study take?**
   It depends on what we are investigating. In the context of research projects it can take one and a half to two years at least.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We do use the packages in Matlab. The toolbox in Matlab has been quite useful. Apart from that we have used some packages that are very available in the public domain
   For the simulation model, It depends on what you want to do. I have used CFD, energy simulation software, self-coded analyses.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No, I haven't developed my own.

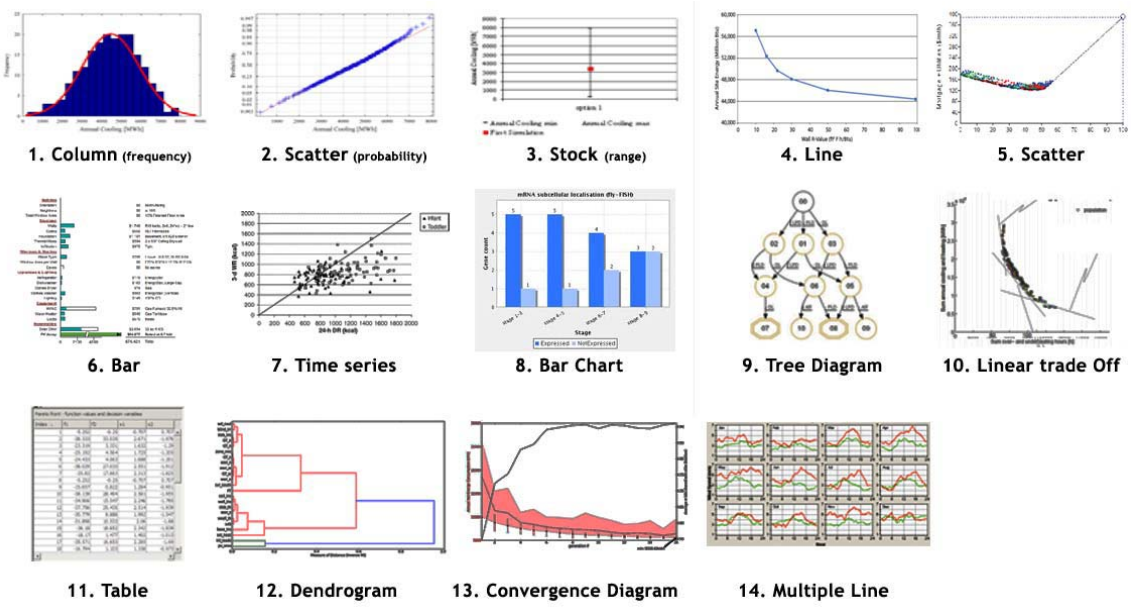
Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   It depends. For large scale projects i was looking for institutional buildings with many sub zones. We have done offices, schools and residential.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   It depends on the problem
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   It depends on the problem
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    It depends on the mathematical nature of the problem. You have to do some sort of preliminary investigations of the problem before you decide what kind of algorithm you are going use. Actually, it is half art half science ... I can't give you a set recipe. if you try to impose a method on a problem then often it doesn't work. You have really to play with the problem a little bit and try to understand the nature of the problem and then figure out what method is the most appropriate. There are certain things that you watch out for. You watch out for how well structured and how well posed your problem is, whether heavily constrained or not heavily constrained, whether it is essentially a linear problem or non linear problem or if it is categorical problem. Also you see if your problem requires heavy simulations then you want to be able to search the parameter space efficiently. These are the kind of things you look at and then you assess. It really depends. You have to play around bit.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    Yes. When a problem is simulation based then you want to be careful about reduce the amount of computational time. In such cases you can take advantage of something like neural networks or cringing to derive statistical models so you don't have to run it all the time.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Not yet
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
       Depends on the problem. sometimes we want indoor temperatures within a certain range. Or we want to minimize emissions or minimize cost of investment. Alternatively, one may have specific targets that you want to match as closely as possible.
    b) **What kind of constraints do you set for optimization?**
       the constrains are primarily to define the feasible domain
    c) **What kind of stopping criteria do you set for optimization?**
       It depends on the algorithm you use. You run a number of iterations and see if you are happy with the outcome or if your parameters stop changing
14. **How do you avoid the insolvable and infeasible solutions space?**
    There are two problems there. If your problem doesn't have a feasible solution that means you designed the problem wrong. So you have to be careful how about problem formulation. If your problem is formulated correctly but you are getting stuck in infeasible space, it means that the optimization technique/strategy is not suitable for the problem.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    In any case one is better off monitoring the progress of the optimization. So you have to do a lot of preliminary work to check your model. 80% of the work is to formulate the problem well. You have to make sure that your problem has a feasible domain; you understand the nature of the problem; you pick the right technique; etc.. Have you scaled the objectives correctly, are you putting the right weight or have you set the right termination criteria. So you are looking to different issues at different stages

Output

16. **Do you have GUI for your own optimization tool?**
    no . We post process results depending on how we want to see them.
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    We usually use the line graph to follow what is going on in the course of the optimization (time series plots) , but then we use anything that make sense to interpret the outputs: bar charts (8) to tables. We use scatter plots (9). I use line (4) a lot and I use table (11) most, scatter (5) and time series (7) and bars (8).



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    There are opportunities where one needs a formal process and optimisation has a role in that.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I don't think that is the right question . I think it is irrelevant to ask how it fits in the design process because for that you need to give a definition of the design process and who owns the design process? These are problem-solving tools for engineering problems. if you need to engineer the facade of a building and it is complicated then you can get use optimisation

techniques to help understand the problem. likewise if you need to compare technologies for a building, it can be formulated as an optimization problem. but I don't think you can generalize where and how it should be used in the design process.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    It depends. Who needs it and who is comfortable with it. We can certainly get people who find it useful but you can't solve a whole part of a process or design a building. So it is very problem dependent.

    But if we have more robust tools that can help formulate the problem then I think it could be used more widely as a platform to make certain areas more accessible or certain parts of the design better understood.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    Optimisation is not integrated in practice because people who practice are not always tuned to understand mathematical representation of a problem. The user of optimisation should be anyone who is able to understand the problem numerically.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

    Same as 22.

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

    Perhaps. Not if they were slapped on as black boxes.

24. **Which tools would you recommend?**

    Depends on what you want to optimize.

25. **What features would you like to find in future tools?**

    Better public domain packages integrated with open-domain, object oriented analysis tools.

IEA Task 40 Interview with Brian Coffey, LBNL, USA

Interviewed: 29 December 2010 (BCoffeyatlbldotgov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**

-M.A.Sc. Building Engineering, Concordia University, Montreal, Canada
-PhD candidate, UC Berkeley
-visiting scholar / graduate student researcher, Lawrence Berkeley National Laboratory
-part-time Environmental Designer, Atelier Ten

2. **Do you consider optimization aspects of NZEB design in work? What kind of optimization technique do you use? (Sensitivity Analysis ,Uncertainty Analysis Optimization, others)**

-Yes, looking for model predictive control with simulation tools
- in real time ...
- calibration
-controls optimisation...
-Using optimisation to predict...
-control strategies

3. **How many projects or case studies have you performed?**

One large case study (chilled water storage system) with six researchers over one year
5 to 10 smaller cases

4. **Approximately, how long does each project or case study take?**

Difficult depends on the cases and their context (anywhere from 1 day to six months)
It depends: Model Development , Model calibration, Optimisation work
I do sensitivity analysis during model development

5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
6. **Did you develop your own optimisation algorithm? (if yes, which programming language)**

-I generally use GenOpt, but have used Matlab in some cases. I wrote a genetic algorithm in java for use within GenOpt.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**

-Commercial (office and retail)
-High end buildings

8. **How many zones do you address when running optimizations? (Single zones – Multizones)**

I am mainly concerned with (extended) HVAC systems with single zone or no zone
Usually a few as possible to minimize runtime

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

-Control variable, set points, supply temperature, operable window (window position and operable shading)

-Optimizing for a particular hour

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

If I need a global optimizer and can spare the time, I usually use a genetic algorithm. If I only need a local optimizer and/or need precision and/or speed, I usually use the Hookes-Jeeves implementation in GenOpt.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

-Occasionally use neural networks, but generally stick to physically meaningful models.

-Multi dimension interpolation

-No fuzzy

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

-If it is an existing design problem, then do calibration, keeping an eye out for potential errors in model and faults in system

-Given a design problem first do parametric analysis and sensitivity analysis

-People want to know more about trade-off rather specific figures

13. **Under which setting you run you optimization what is your methodology?**
    a. **What kind of objectives do you set for optimization?**

    Usually energy minimisation, sometimes peak demand or energy cost

    b. **What kind of constrains do you set for optimization?**

    Usually comfort, system capacity

    c. **What kind of stopping criteria do you set for optimization?**

    The standard stopping criteria for whatever algorithm in use, plus a computation time criteria if used in an online controller.

14. **How do you avoid the invisible solutions space?**

Only single objective (mainly control)

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

I go back fix the error, revise input

Output

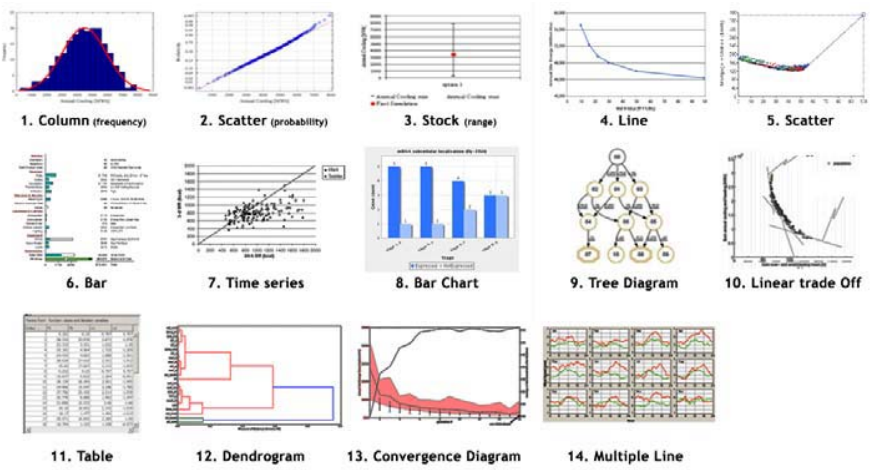
16. **Do you have GUI for your own optimization tool?**

no

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Line graphs more like figure 4 but several lines

Tabular graphs representing the basecase versus the optimized case



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

From two sides:

- In the early phases of design, as an iterative tool alongside parametric analysis
- To determine near-optimal control for integrated systems, both during the design phase and during operation

20. **Who will be the user group? Should optimisation techniques used by engineers only or architects tool?**
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

Developers: Shortcomings

22. **What the major obstacles of integrating optimization techniques in NZEB design? Can you rank the obstacles from most difficult to easiest?**
    - The certification mindset – simulation is most commonly used in practice as part of a certification procedure, rather than as a tool to aid in design decisions, and as a result our modelling software and modelling personnel tend to focus more on the intricacies of defining base cases and defensible methods of simulating particular systems, rather than focusing on ways of exploring the design space.
    - Standard simulation tools and data are not well suited (eg. for early-phase design optimization, would be good to have representative annual weather files that were less than 8760 hours).
    - Tool interface
    - Output visualisation (more intelligent)
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
24. **Which tools would you recommend?**
25. **What features would you like to find in future tools?**

    - Better interfaces, mote intuitive, better usage friendly, visualizing the results, cloud computing.

IEA Task 40 Interview with Chad Corbin, Univeristy of Colorado, USA

Interviewed: 17 January 2011 (chad.corbinatgmail.com)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   B.S. Mechanical Engineering, Cornell University; M.S., PhD Candidate, Building Systems Program, Department of Civil, Environmental and Architectural Engineering, University of Colorado at Boulder.
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   In our modelling work we first look at the sensitivity of different parameters that affect energy use in US commercial buildings. We review modelling techniques for the types of buildings that we are considering and look at previous work that is been done either heuristic control or quasi-optimal control. We then construct models of these buildings, making the parameters we can control in the building automation system variables. Then we subject these buildings to a number of different optimization case studies, looking at the effect of one control variable, versus two, versus three. We also study how to discretize the control variable over the time, the boundaries of the control variables, and time frame or season under which we run the optimisation. We look at all of these different aspects of the optimisation before we run hundreds of optimisations and try to understand what patterns emerge.
3. **How many projects or case studies have you performed?**
   We have been involved in two studies: one funded by a start-up company here in the USA, one funded by Technische Universitat Dresden. If the first, we modelled a number of commercial buildings in downtown Chicago and subjected those buildings to off-line control optimisation in order to utilize passive storage in the buildings mass to mimimize energy consumption and cost under different electrical pricing schemes. The second study involves TABS (Thermally Activated Building Structures). They are typically very massive concrete buildings, in which their heating and cooling elements are embedded into the structure of the buildings. In these studies we would manipulate and supply water temperature and supply air temperature simultaneously to arrive at the lowest cost and energy operation subject to comfort constraints.
4. **Approximately, how long does each project or case study take?**
   Approximately 9 months on the first project. I have been working on the second project for over a year now.

5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**

   We have a set of codes that we developed in Matlab. The modelling engine we use is EnergyPlus. We are currently exploring the use of the ISO 13790 specification (simple hourly method) for energy calculations in order to have a computationally lighter weight model. It is time intensive to do optimisation in EnergyPlus; the biggest challenge is the simulation speed. Ultimately, we are trying to optimise buildings in real-time. For example, we would receive prices and weather forecast the next 24 hours, initialize an optimisation and allow the optimision an hour to come up with the next control strategy of the building. In EnergyPlus, optimisation is difficult because the simulation times are too long for a real-time optimisation.

6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**

   Yes in Matlab.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**

   The work at the University of Colorado has been focused commercial buildings. The work I do in private industry is focused on residential buildings.

8. **How many zones do you address when running optimizations? (Single zones – Multizones)**

   For commercial buildings we have been using a 15-zone model. We have a ground floor model, a middle floor model for all floors between the ground floor and upper-most floor, and an upper floor model. All three are modelled with four perimeter zones and one core. For residential buildings, we typically simplify the model into one thermal zone.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Primarily we manipulate the set point schedules we would be able to control through a building automation system.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    We use a customized particle swarm algorithm, which is a meta-heuristic algorithm. It is similar in some ways to evolutionary algorithms as it follows simple rules of fitness, but it is not a genetic algorithm. Basically, it simulates the swarming behaviour of flocking animals and tends to work well for 'black-box' problems. We don't use deterministic algorithms because the problem is a black box and we don't have access to the underlying equations their derivatives. Even if we did, the objective function is discontinuous. Energy consumption in buildings is a function of physical process and control decisions that enable or disable certain characteristics. This can result in discontinuities in the model and provides challenge for many of gradient search techniques that are common. We also see a lot of equivalence in solutions and regions of insensitivity. We've tried Quasi-Newton and Nelder-Mead simplex, but found Particle Swarm to out perform them both in terms of speed and ability to find the minimum.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No, in these projects we do not use neural networks. Our goal is to develop new near-optimal heuristics by looking at the time series of control decisions and extracting rules, however we have not yet settled on a methodology.

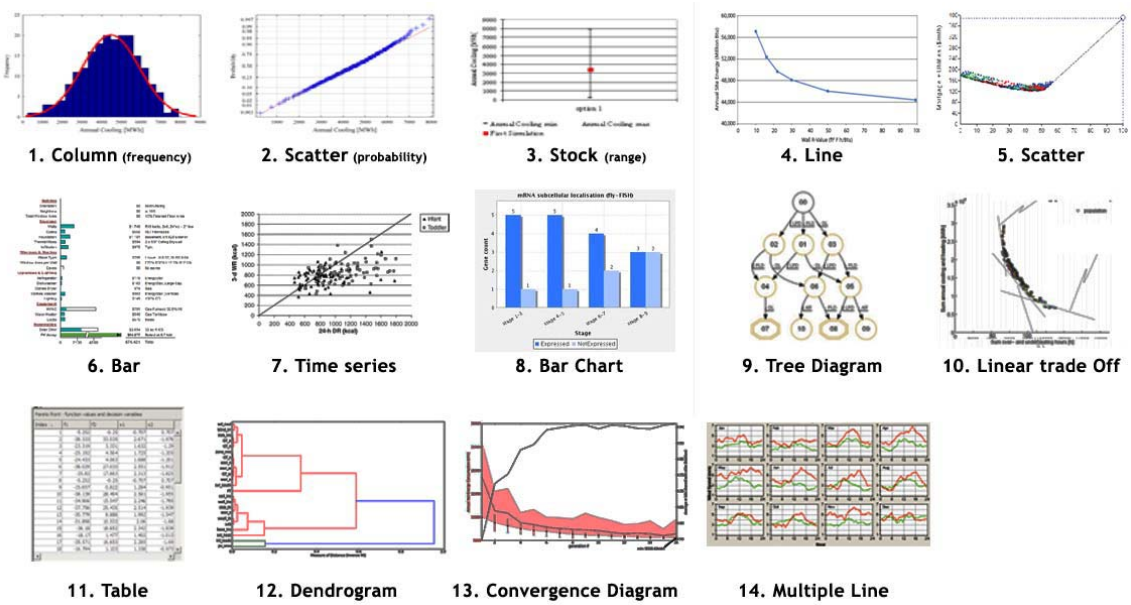
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

Currently we assume perfect knowledge of both building and forecast. There is another student in our group that will be looking at using Monte Carlo methods to address the sensitivity and uncertainty issues.

13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    We have looked at single objective and multi-objective optimisation, however the multi-objective optimisation is implemented as a single objective cost function plus penalty terms; it is not a true multi-objective optimisation. Most our optimisations are energy and or cost of energy focused with comfort penalties.
    b) **What kind of constraints do you set for optimization?**
    We use penalty terms and constraints in the optimisation work to both guide the optimizer away from infeasible regions and also to consider the impact of thermal comfort boundaries on the optimisation. Constraints can be boundary or equation based.
    c) **What kind of stopping criteria do you set for optimization?**
    Primarily we use a measure relating to how well converged the solution is by looking at the swarm particles and determining how closely clustered they are in the n-dimensional search space. We have also added criteria that will eliminate particles if they become stuck in the same local minimum. For real-time optimisation, we have added a time criterium.
14. **How do you avoid the insolvable solutions space?**
    Generally our decision variables are bounded by the physical limitations of the building and comfort limits. We won't allow the optimiser to explore solutions that are physically infeasible. For example, we do not allow the optimizer to use a supply air temperature below 8 degree Celsius. We do not allow the optimizer to search regions outside of the range of normal operation.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    It is rare because we are choosing our boundaries by box bounding our decision variables within the physical limitations of the building. Because we bound our variable to feasible values our model typically does not have problems. We occasionally have some errors that are the fault of an un-trapped exception within the simulation program but we have no way to foresee that kind of problem.

Output

16. **Do you have GUI for your own optimization tool?**
    No..
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    Mainly time series (7). We are effectively performing time series optimisation of control variables. Graphs are generated from scripts written in Matlab.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    For the current work that we are doing with HVAC control optimisation we are evaluating existing buildings, which are beyond the control of the building designer. We can only optimize what is already there. However, if performed at an earlier phase incorporating HVAC design and control, we would be able to influence the size of equipment by optimising control strategies that prevent over sizing the chiller and the boiler plants. We haven't been involved in an effort like that, but we can definitely see how control optimisation prior to equipment selection would be a benefit in both capital and operational cost.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    At early design stages you would be able to choose between different glazing options, different construction types, different orientations, shading, equipment and control strategies. Optimisation could certainly benefit the overall design when done early. I think as an early stage design tool it is useful to help generate ideas and explore possibilities.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    In my opinion it requires a bit of specialisation; it is too easy to put bad assumptions into a model and see results that are unrealistic. Results are not really optimal if the underlying model is not correct. This work requires a broad knowledge base and an understanding of buildings and building models. If you put an optimisation program in front of someone not familiar with the underlying physics, you may come up with an interesting result, but I don't think they would be able to tell you why. That is the problem. You need a solid understanding of what is going on. You need to be able to answer the questions: Why did we find this optimal result? Why is this solution better than others? What are the characteristics that lead to this? BIM can get us closer,

but it isn't quite there yet, and you will always need to be able to interpret the results. I think as an early stage design tool it could useful to help generate ideas and possibilities by a non-specialist, but the critical optimisations need to be reserved for somebody who is specialised.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    I don't think that optimisation is well integrated now because there are always budget and time constraints on the design team. Even if it were, you wouldn't be able to guarantee that the results would be implemented simply because there are other forces at work in projects. Integration requires a cultural shift and education of the design team, including architects, engineers and even clients, on how optimisation works, the improvements it can bring.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - The biggest challenge in our work is simulation speed. Modelling and calibration are also very time consuming processes. Being able to model, calibrate and simulate quickly allows you to explore more options.
    - The exchange of models between different software: architectural vs. energy vs. mechanical, etc.
    - Model mismatch and uncertainty of model input.
    - Awareness in the design and engineering communities.
23. **Would you use optimization tools if they were integrated unto an energy modelling tool?**
    - Yes, I would. That would be a great addition. We aren't very close right now.
24. **Which tools would you recommend?**

    Matlab, its optimisation toolbox, and GenOpt.
25. **What features would you like to find in future tools?**
    - Faster models. Some of the work I would like to do would take years with current simulation tools;
    - Robust BIM programs that cut across all aspects of building design and operation. For example, we have programs that allow architects and engineers to share designs and automatically check for collision between ducts and structures. We need better integration of these tools with energy models that can automatically show us the implications of design on performance.
    - Automated optimization. For example, you define the problem and the tool does the sensitivity testing for you and figures out which variables need to be optimised, how best to discretize the decision space, how much control history and forecast are needed.

IEA Task 40 Interview with Dr. Natasa Djuric, Sintef Energy, Norway

Interviewed: 28 December 2010 (natasamdjatgmaildotcom)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Mechanical Engineer holding a PhD retaining building optimisation for heating and ventilation systems
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Currently we are working on a project on zero emission buildings and I am working on guidelines for lifetime commissioning of zero emission buildings and there optimisation was suggested on different levels, for example sensitivity analysis at design phase, optimization of control parameters in optimization of different energy sources. In fact all those solutions for zero emission buildings they can work if you are looking at one aspect, for example the impact of installing a certain insulation, or equipment in relation to the performance. Therefore, it is very important to do some sensitivity analysis for some parameters. We are working on this and we are recommending the use of optimisation.
3. **How many projects or case studies have you performed?**
   Between 5 to 10 case studies.
4. **Approximately, how long does each project or case study take?**
   It can take some time up to a month
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   I use GENOPT and Matlab but not at the same time with EnergyPlus.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No.

Methodology

7. **Which building typologies have you used optimization for and in which climate? (Residential, Offices, Retail, Institutional)**
   Usually most of the case studies are office buildings or universities.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Depends, when I create zones I created detailed model usually more than 10 zones and up to 20 and then I do the optimisation for systems and connect all the zones.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Usually I optimise envelope, comfort, heating and ventilation systems, size of equipment and properties of equipments, controls and also some parameter optimisation for advanced control

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    I use deterministic not evolutionary algorithms. In Matlab I use sequential quadratic programming (SQP). I use linear optimisation for some simple task and in Genopt I use Hook-Jeeves and some hybrid methods and also the Golden Section Method for single parameters.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    I did some sensitivity and uncertainty analysis for single components. We published recently one article* in Energy and Buildings on data fusion, on how to estimate heat pump performance and then we developed this basic model and calibrated to verify the model input. Then we did some sensitivity analysis to help us in calibrating the output and establish the uncertainty values. This help me to know where to set up input limits for optimisation.

    *Natasa Djuric, Gongsheng Huang, Vojislav Novakovic, Data fusion heat pump performance estimation, Energy and Buildings, Volume 43, Issues 2-3, February-March 2011, Pages 621-630

13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**

       I don't use multiple objective criteria. The objectives are energy consumption, electricity or heating depending on the problem, comfort.

    b) **What kind of constraints do you set for optimization?**

       Depending on the problem, the codes or technical specifications. Most probably comfort constraints.

    c) **What kind of stopping criteria do you set for optimization?**

       Maximum number of iterations and accuracy

14. **How do you avoid the insolvable solutions space?**

    I didn't try to analysis this deeply but I follow a trial and failure approach. I revise the results and check if they are acceptable.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    I revise the input and change some parameters. I just analyse the problem until it is solved.

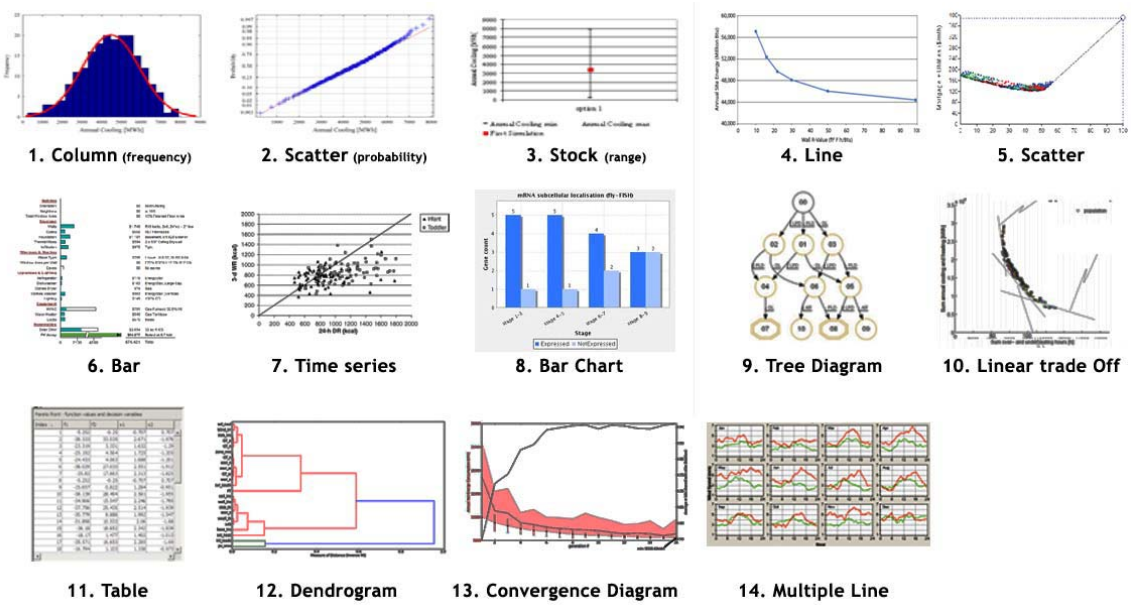
Output

16. **Do you have GUI for your own optimization tool?**

    No.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    2 or 3. 5 is good and 6 for rating of parameters.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I see the use of optimisation is very important for systems selection and systems sizing. Also for the energy supply systems and energy heat recovery adjustment in buildings. Also load matching or mismatch and model predictive controls (MPC) in relation to energy storage in the building. Set point temperature for heat pumps. Also it is applicable in construction and operation.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    It is already very important for systems sizing. But I am not sure how architects think about the iterative approach of optimisation but I see it very useful for geometry and positioning of the building and utilising daylight and windows openings.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    All of them but then architects can use it for different parameters.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    Cancelled.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Misunderstanding: I think that optimisation in the daily practice is misunderstood. People don't understand what mathematical optimisation is.
    - Very complex and detailed tools and the settings are complex and also simulation
    - Complex techniques
    - Tedious and time consuming

- No appreciation for the importance and effect of optimisation by project stakeholders
- Quality of optimisation results
- Low return
- Difficult to categorize and analyse the results
- No encouragement or requirement to use optimisation
- Too much parameters for zero energy emissions
- Difficult to calibrate model
- Not part as a standard practice
- In real practice people like to do what they know and done already

23. Would you use optimization tools if they were integrated into an energy modelling tool?

- yes

24. Which tools would you recommend?

- Genopt with EnergyPlus
- Matlab

25. What features would you like to find in future tools?

- Interoperability and the seamless exchange of models from simulation tools to optimisation tools allowing reviewing the input and output easily in order to start the optimisation work.
- Highly detailed model resolution
- PV and renewable energy systems
- Allow multiple range and objectives of optimisation
- Present and explore the output in a better way
- Better data analysis and mining and interpretation of output
- Show easily the most influencing parameters and kind of rating for solutions and parameters

IEA Task 40 Interview with Elaine Hale, NREL, USA

Interviewed: 8 April 2011 (ElainedotHaleatnreldotgov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Chemical Engineering
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes, in my Ph.D. I used numerical optimisation. My PhD is in chemical engineering but I wrote a particular kind of [optimisation] solver for my PhD project and then I did post-doc work in the applied math department at Rice University doing some other kinds of optimisation. Before coming to NREL I had not applied it [optimisation] to buildings. The studies I have done at NREL are national policy scale studies looking at 16 different climates for particular building types. We use a tool called Opt-E-Plus, which is an in-house research tool here. You can do perturbations studies with it or do optimisation. Opt-E-Plus supports bi-criteria optimisation problems that minimize cost and energy use simultaneously. At the end of the study we would post-processing the optimization results by doing some additional perturbations. The post-processing was similar to a sensitivity analysis, but with bigger steps. When I think about sensitivity analysis from a mathematical point of view, it is often in the sense of taking numerical derivatives of the objective function subject to variables. Opt-E-Plus only provides (often large) discrete changes to your building model; there is no derivative information. We call that perturbation, where we are doing a big change. By perturbing the approximately optimal point yielded by the optimisation, we could see what kind of changes make the biggest difference at that point of solution space.
3. **How many projects or case studies have you performed?**
4. **Approximately, how long does each project or case study take?**
   I did four large scale studies, over the course of two years. Each study had one to three prototype buildings, each optimised separately for 16 climates. Each optimization plus post-processing step contains two to seven thousand simulations.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   Opt-E-Plus and the simulation engine was EnergyPlus
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, I developed a post-processing algorithm in Delphi. It's baked into Opt-E-Plus, which is a Delphi program. It is not really an optimisation algorithm---it's an algorithm to do multiple optimisations to find multiple models that meet your criteria. It often doesn't make sense to give someone a single optimal point because there are a lot of reasons they might not like that point. So this algorithm tries to find a diverse set of solutions, that is, multiple models that meet the criteria and are significantly different in some way. Some people might prefer one model and

some prefer the other. So there is a whole set of them that all meet the primary design objective.

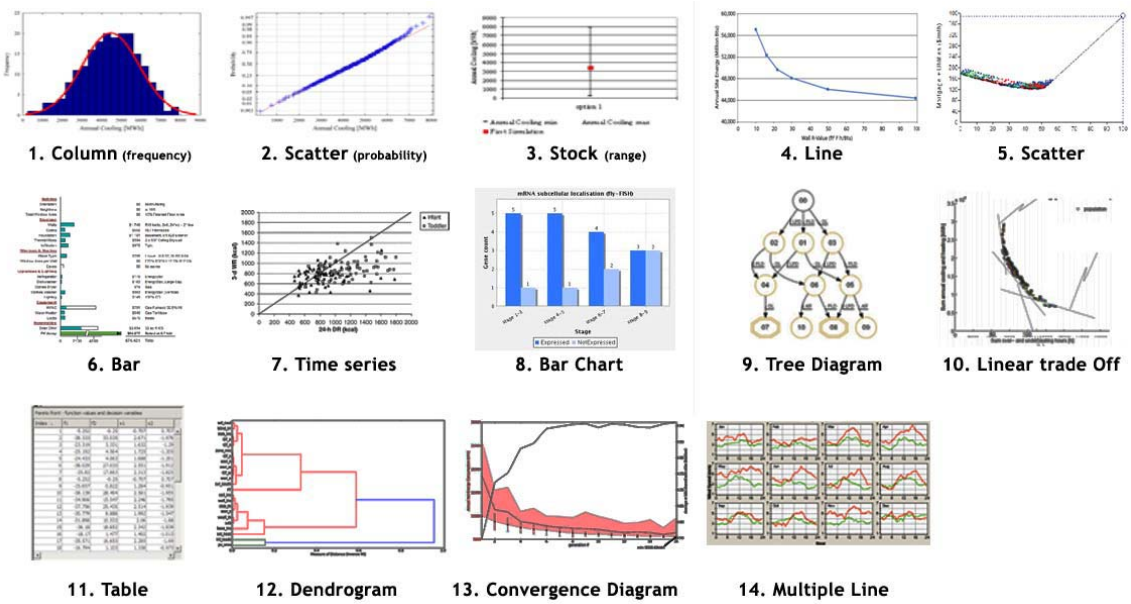
Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Commercial buildings.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Those models are pretty small. They have multiple zones, but under 20 total.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   We had construction types, window to wall ratio, lighting power density, PV systems, HVAC efficiencies.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    It is a greedy heuristic method for solving problems that have two objectives.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    Not typically.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Yes and no. We have a lot of experience in-house to know which variables matter. As I mentioned before, we did a perturbation study as post-processing work to get more detailed information about the optimal point. We end up with something like a relative ranking of the discrete changes (from baseline) that went into the chosen model. We do not yet incorporate uncertainty analysis.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
       There is always an economic objective and energy objective.
    b) **What kind of constraints do you set for optimization?**
       No explicit constraints. We typically apply the standard to the baseline building and then the optimisation problem is built around discrete changes in the model in which any constraints are baked into the overall measure.
    c) **What kind of stopping criteria do you set for optimization?**
       The algorithm goes until it can't go anymore. It is almost graphical as it traces out a minimum cost curve, so it doesn't have a numerical tolerance.
14. **How do you avoid the insolvable solutions space?**
    The way this algorithm works it is always tracing out the cost curve starting from the baseline building. The discrete changes allowed by the algorithm are designed so that you always (in the ideal case) end up with a simulatable model.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    It does happen and the program hobbles over the failures. You will not get the best results because you are missing a part of the solution space you are trying to explore. But if the program crashes for any reason you can pick back up in the middle of your runs.

Output

16. **Do you have GUI for your own optimization tool?**
    Yes
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Mainly number 5 the scatter plot, 7 and 8, but it depends because they are used for different things. So if I am debugging a model then I am probably will look at time series to get detailed information to figure where my model is running into problems. But if I am writing a report then I am going to need more of a summary. Then I will take 8 (bar chart) or a table. For post processing and checking the diverse solution set, I make tables and a tree diagram (9). That shows your main optimal point and the other feasible points derived from it.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    It should be integrated during the building design and the NREL Commercial Building Research Group is a big believer in doing a lot of design work using optimisation. Starting from the conceptual stage, we promote having architects and engineers all talking and reviewing different designs. I think you should be doing most of your optimisation work at that point. So you should be able to quickly make models from an architectural stand point and define what you want to optimise over there and let it run to give you other options. Also I would include geometry in the optimisation, so optimisation has to be there at the very beginning.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Architects and engineers
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    Architects and engineers. But optimisation is not there yet to cater to both. There are not enough interfaces for different audiences.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

Architects and engineers should be able to come up with a couple of concepts. They should be able to list the parameters that they are looking to play with, like stretching the building horizontally, making it taller, etc. all while satisfying floor area and space type constraints. They could end up with a range of optimal models or solutions with a big parameter space focused on envelope. They would then pick a solution and fix most of the envelope design and optimise the HVAC. So it is an iterative process and the design team should be doing optimisation throughout the process.

Developers: Shortcomings

22. What the major practice obstacles of integrating optimization techniques in NZEB design?

- The interfaces. There need to be an easy way that allows people to do their kind of studies and design. They need to be easy to use for researchers and designers.
- When we show people the optimisation they say, "It is nice, but what are the error bars on that optimisation point?" What can you say knowing that the cost is so uncertain? There are also other uncertainties on the energy side too. So that needs to be well addressed.
- Matching the workflow
- Be able to rerun optimisation
- I get the idea that there are a lot of people in industry who do not do simulation. People want to see real, physical buildings next to simulation results, which is pretty hard because energy use is often driven by occupant behaviour.

23. Would you use optimization tools if they were integrated into an energy modelling tool?

Yes. You have to design your prototype model first, so you need some sort of modelling tool to build your model. Then there should be some other (related) tool to set up the optimisation problem and run it.

24. Which tools would you recommend?

- BEOpt for residential buildings. And we have plans to fold optimization into OpenStudio.

25. What features would you like to find in future tools?

- They should have interfaces that allow architects and engineers to use optimization throughout the design process.
- Also we have to have a list of buildings with their performance.
- You should be able to do modeling and optimization in a smooth, streamlined way.
- You should have automatic checking of input quality and be able to check whether the simulation result you are getting passes the laugh test (against your input data and general knowledge).
- You should be able to handle uncertainties throughout the optimization.

IEA Task 40 Interview with Mohamed Hamdy, Aalto University, Finland

Interviewed: 12 January 2011 (Mohamed.Hassanattkk.fi)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Mechanical power engineering and energy savings in buildings.
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Yes my research is focus on optimal integrated building solutions. We are using simulation tools called IDA ICE, Swedish software, and we are trying to create a combination between this building simulation package and optimisation software. We use two optimisation toolboxes one from Matlab and the other is Genopt. I start with sensitivity analysis to give us an indication or direction on the most sensitive parameters. Then I start to formulate my optimisation problem.
3. **How many projects or case studies have you performed?**
   I have a three years experience in this field. I did about 4 optimisation cases.
4. **Approximately, how long does each project or case study take?**
   This is difficult to answer but it takes approximately 4 month per case.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   The two toolboxes in Matlab. The optimisation toolbox and direct search and genetic algorithm toolbox. Additionally I work with a college here using GenOpt .
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   In fact I made two developments to Matlab. In the Matlab toolbox we focus on genetic algorithms but we found that it is not effective to use genetic algorithms only. Also when you tack a building design optimisation problem you normally have two types of optimisation variable, discrete and continuous variable. In the current version of Matlab, only continues variables are addressed. Therefore, I developed the optimisation algorithm of Matlab to be able to handle discrete and continuous variables. The second development was the creation a combination between genetic and deterministic algorithms to get higher performance.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Mostly residential: single family or detached houses but we have a case of office building. Currently, I am working on a single family house aiming to address optimal solutions for NZEBs in cold climates.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**

Multizone models. In one case study we simplified the house into three zones representing the building floors and the staircase. But we decide zoning based on the expected results. It depends on the objective. If you only focus on energy you can make a simple model, if you focus on thermal comfort and operative temperature you focus on multizones models addressing walls surfaces, windows area, etc.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Our research focus is integrated building solutions. So we focus on envelope including insulation (walls, roofs, and floors), window types (U-value, G-value, T-value) infiltration rates, shading. Concerning systems we focus on efficiency of the heating system (ground source heat pumps, direct electricity, oil fired boilers) heat recovery systems. Also we focus on control strategies for night ventilation. So we focus on all energy saving measures that can be used in low energy buildings.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Using only deterministic or only evolutionary algorithms is not effective. For example, in Matlab only continuous variables are addressed. In building design there are many design variables that you cannot address as continuous for instance the U-value of window cannot be taken as a continuous variable. Therefore, I developed the optimisation algorithm of Matlab to be able to handle discrete and continuous variables. On the other hand, if you use genetic algorithms only, the algorithm will address only non linear constraints as a penalty function which is not effective. Also in genetic algorithm the variables gets selected randomly through the initial population. It is possible in this case that the initial population has bad or low values, which will require very long time to get reasonable results if we used genetic algorithms alone. So I tried to make a combination by using deterministic algorithm to prepare a good initial population to save time then let the genetic algorithm hook up and continue the optimisation faster. Therefore, I created a combination between genetic and deterministic algorithms to get higher performance.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    Yes, I tried only multi-dimension interpolation and found it could be good approach for continuous variable but bad for discrete variables.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Actually, I do sensitivity analysis after and before the optimisation but I don't record the results. I do that only to guide my endeavour.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

       In all my cases I address multi-objective problems. My objectives are mainly, primary energy or heating energy, CO2 emissions, investment cost, life cycle cost and thermal comfort because we have here in Finland very strict comfort criteria and we try to test the influence of comfort on energy consumption.

    b) **What kind of constraints do you set for optimization?**

       Usually we use constraints on investment cost because you cannot put very high additional investment cost. Also we add constraints on thermal comfort in the form of degree hours. So if you increase the insulation you get an overheating problem in the buildings so we make a constraint on overheating. The same for overcooling.

    c) **What kind of stopping criteria do you set for optimization?**

For genetic algorithm, I usually use the maximum number of generations as a stopping criterion. For pattern search, I use a certain size of Mesh tolerance as a stopping criterion.

14. **How do you avoid the insolvable solutions space?**

Actually, we design our problem well to reduce the space of infeasible solutions. On the other hand, we use a penalty function for unavoidable infeasible spaces.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

I neglect the failed simulation point completely. I try to keep all the solution points that I get during optimisation, and then I sort them. In this case if I have some failed simulation runs I neglect the results of those failed runs. We can determine the failed run by checking the simulation time (e.g., if the simulation run is very short or very long, it gives indicator that this run has a problem).

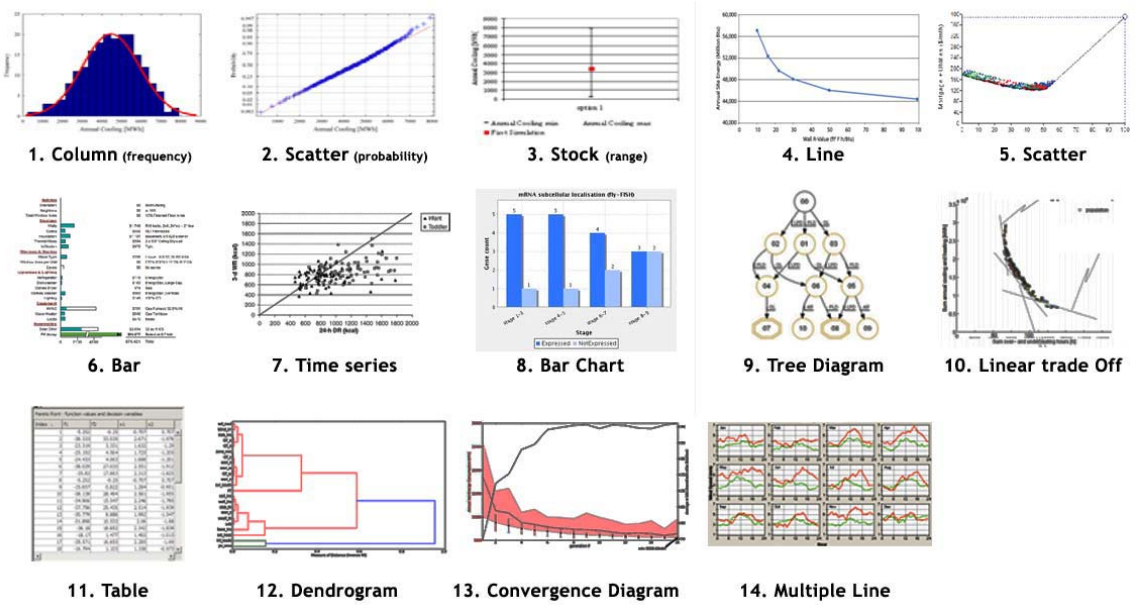
Output

16. **Do you have GUI for your own optimization tool?**

Actually I developed a GUI but only for our use in the laboratory. Its limited to the case studies, but we are looking to develop a generic GUI.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

I mainly use number 5 looking for the Pareto Front.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

I think simulation-based optimization is a promising approach to achieve NZEB. However, compatible competitive design should be defined. Advanced software packages are needed to simulate advanced technologies such as (Micro-CHP, PV, PVT, solar collectors, Micro-wind, etc).

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

I think in early stages of design

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    Till now researchers. But I think in near future, advanced Integrating Optimization Tools would be available with suitable interface. To address pre-defined solutions.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    If simulation-based optimization design tools are developed with friendly generic graphical user interfaces (GUIs).

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Time of simulation (i.e., most of energy saving measures, for example natural ventilation, increase significantly the time of simulation).
    - Indicators of NZEBs are still under negotiation.
    - Most of the available simulation tools can not address advanced technologies such as Micro-CHP.
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    - Of course yes. But it is not easy to trust the results.
24. **Which tools would you recommend?**
    - GenOpt is easy to use.
25. **What features would you like to find in future tools?**
    - simple graphical user interface
    - Good output visualisation with suitable indexes
    - Applicability to implement different configuration of heating/cooling systems
    - Applicability to implement the most advanced energy saving measures and technologies

IEA Task 40 Interview with Ala Hasan, Aalto University, Finland

Interviewed: 06 October 2011 (ala.hasanataalto.fi)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Engineering (Mechanical engineering)
2. **How do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   We have a group for optimisation in buildings. We intend to use combined simulation-optimisation in achieving the NZEB objective. Our approach is by studying the problem first to define the important variables to be included in the optimisation. We do sensitivity analysis and some simulation in the beginning before using optimization, because if we don't do so there will be many variables and the problem might be very big.
3. **How many projects or case studies have you performed?**
   The number of projects we worked on are about five.
4. **Approximately, how long does each project or case study take?**
   It depends on the project. I would say 6 months for each case.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We use Matlab and Genopt. In Matlab we modified the existing algorithms. In Genopt we added multi-objective algorithms to the library. We combined them with IDA ICE.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, we did it in Matlab and Genopt.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Single Family house, block of flats and office rooms in Finnish climate. We didn't work on schools but we might work on it.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   It depends on the objective. If we are studying energy in a house, we can represent it as a single-zone because it will have minor effect on energy calculation results. But when there is thermal comfort as a criterion or objective we would need a multi-zone model, because just lumping all zones together would lose the accuracy of estimation of the thermal comfort.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   We started with the building envelope, orientation and then control, thermal comfort, energy supply systems including renewable energy systems. So we are covering a very wide range of variables.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    In the beginning we used deterministic and then we went to hybrid algorithms. By hybrid I mean deterministic combined with stochastic. For the hybrid we tested more than one available algorithm in Genopt. Now we are mostly using genetic algorithms. We use genetic algorithms for multi-objective problems.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No, but it is in our plan to use it.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    We do only sensitivity analysis prior to the optimisation.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    It depends on the project or the case study. We started with single objective for life cycle cost using Genopt. Then we were doing multi-objective: initial investment cost, energy, carbon emissions, thermal comfort criteria and equipment size.

    b) **What kind of constraints do you set for optimization?**

    Mainly comfort and energy.

    c) **What kind of stopping criteria do you set for optimization?**

    For deterministic algorithms we use target approaching stopping criteria or maximum number of iterations. With genetic algorithms we go for maximum number of generation.

14. **How do you avoid the insolvable solutions space?**

    With evolutionary algorithms, we should be able to solve most problems, but then it is a matter of expense of time.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    By investigating the reasons, retrying and run the simulations and optimization again.

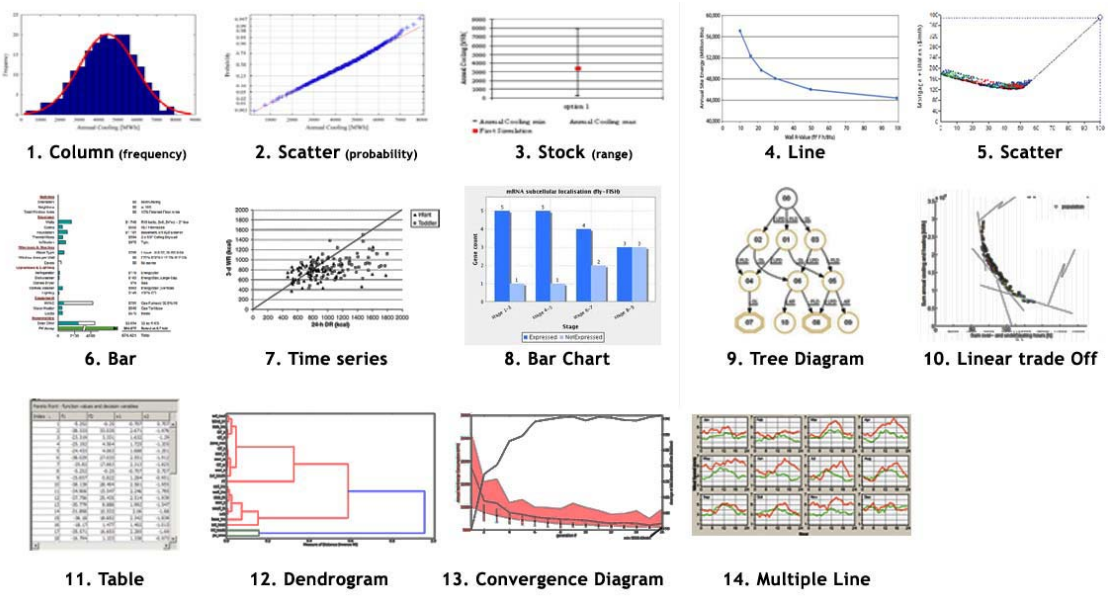
Output

16. **Do you have GUI for your own optimization tool?**

    There is a GUI in Genopt.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    I use number 5 the scatter type for the cost optimality and we use 10 for finding the trade-off. So it depends on the problem.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I believe that there is a great opportunity. NZEB is an excellent example for an optimization problem and available tools should be able to work on it. I see that it can fit better in the design phases of the project.

    Previously, we had a project with some construction and consultation companies. For them as long as business as usual is profitable, optimisation is not too much interesting. But now with NZEB as a target and with the large number of design variables and the multi-objective feature of the problem, I am sure that the attitude will be different towards optimization.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    It will fit more in the conceptual and the design phases.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    I think it is useful for all those tools. It is now mostly used by researchers.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    Optimisation can contribute in the decision making as the solution space is part of the decision making space. For decision makers, we need to come up with a limited number of solutions or options. For example if we find tenths of trade off solutions, it might be difficult to the decision maker to select one.

    Optimization can be more popular for application in the early design phases by developing user-friendly interfaces and tools for optimisation. Also designers should be educated about the benefits of using optimization in order to encourage them to it.

Developers: Shortcomings

22. What the major practice obstacles of integrating optimization techniques in NZEB design?

- How much we can create a user friendly optimisation tool. I think it is not an easy task for a normal user. If you are using TRNSYS, EnergyPlus or IDA ICE the optimisation program has to have a sort of tailor made connection with those simulation tools. This can be seen as an obstacle by a normal user.
- How to convince designers in practice that optimisation is beneficial. First it is to explain to them what is optimisation and how it could be beneficial for them. Because most of designers think it is much like a mathematical approach for academic studies.

23. Would you use optimization tools if they were integrated into an energy modelling tool?

Yes, but it should be flexible enough for all possible cases and different levels of optimisation problems.

24. Which tools would you recommend?

For us we are using MatLab and Genopt with IDA-ICE simulation program. Genopt is good but it is a single objective optimisation tool. We have added genetic algorithms to the library of GenOpt so that it is be able to handle multi-objective problems. I hope that the next version of GenOpt will include our algorithms.

25. What features would you like to find in future tools?

I would like to see ready interfaces for the combination of simulation tools with optimization tools, which could help normal users and designers to easily implement them. Besides, features for more accuracy and time efficiency.

IEA Task 40 Interview with Jan Hensen, Tech. Univ. Eindhoven, Netherlands

Interviewed: 09 June2011 (j.hensenattue.nl)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Architectural engineering
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes, we are researching first of all how to do optimisation and secondly how that might assist in the design process in our profession. We are researching techniques how to automate the design process. Once we have it, for example computing resource, how quickly that will go. I think pretty fast but we don't have any real experience because all these things are under development.
   Also you have to be very careful with the word optimisation because different people have totally different understanding about it. I speak about computational optimisation which is somehow automated. A lot of people think of optimisation like to run a case study and then having different variants of the case study and this they call it optimisation.
3. **How many projects or case studies have you performed?**
   Depends on how you define case study. We did not do case studies for a particular building to optimise it. I do not think that people do automated optimisation in practice or real case studies.
4. **Approximately, how long does each project or case study take?**
   n/a
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We use modeFrontier, which is a very powerful cross industry computation optimisation tool and we couple it with ESP-r. We used also other optimisation tools before like Genopt and a tool from Leiden University called Topgui.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No, but really those optimisation algorithms are a much specialised work it is more for mathematicians optimisation specialist. So this modeFrontier offers many different optimisation algorithms and methods which you can just select from the tool.

Methodology

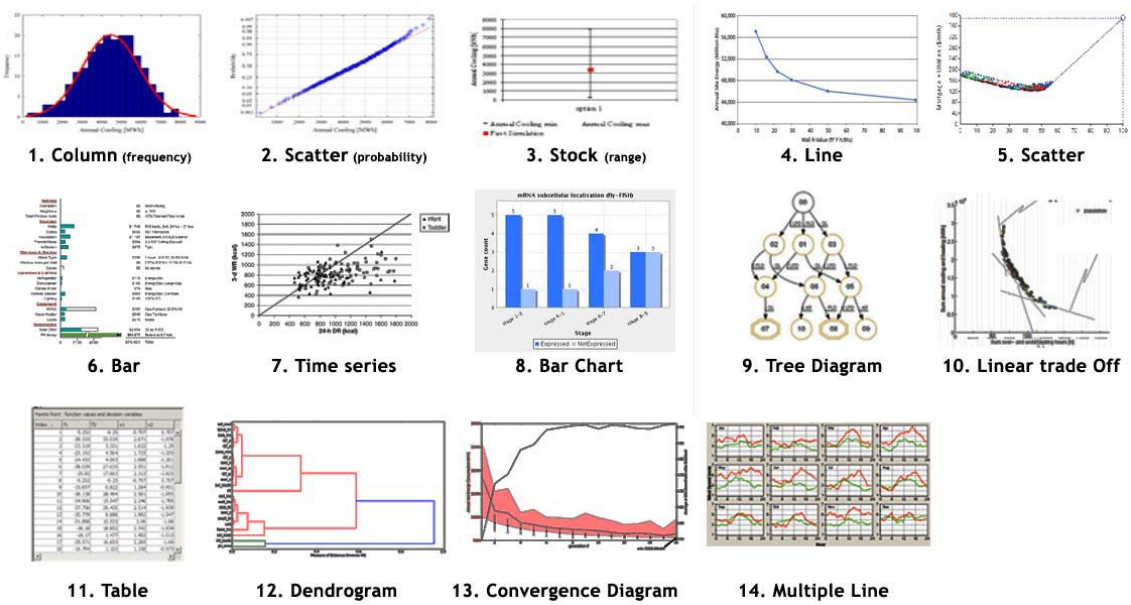
7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**

We are not restricted to any building type or any climate. We are interested in general approach.

8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Multiple zones because zones in the building interact and doesn't make sense to optimise a single zone I think.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   It's mostly the building shell and we have another project that looks at systems and controls.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    We use either. Determining the use of deterministic or evolutionary algorithms is under research.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Yes.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    We use multi-objectives and we look mainly at energy and indoor environment, but since we do optimisation in research we do not include cost. Also we don't have a tool that can predict the cost.
    b) **What kind of constraints do you set for optimization?**
    All solutions those are practically feasible
    c) **What kind of stopping criteria do you set for optimization?**
    Either the number of generations or run time limit.
14. **How do you avoid the insolvable solutions space?**
    We use a good tool to run the optimisation. That was one of the reasons why you selected this tool.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    We have the optimisation coupled to several projects using different tools like ESP-r or TRNSYS or other software. You can copy the modeFrontier script to every calculation engine.

Output

16. **Do you have GUI for your own optimization tool?**
    Yes, modeFrontier has a GUI.
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    The most important is number 5 (an x and y graph with Pareto Front)



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    It depends; a very innovative users/researcher would be able to use this research type of tools so the material is actually ready for them. I think at the moment, optimisation techniques are ready to be used by the most innovative engineers who can use it for every design task. Over time, I see this happening, being integrated and becoming standard for other tools so the number of users will increase dramatically. In five or ten years it will be a standard feature for BPS tools.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I think during the whole design process.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    Personally I think that in the future engineers and architects will use all those computational techniques, whether structural or architectural, and they will be expanded to optimisation and uncertainty and sensitivity analysis. If designers use already simulation tools you can easily in the future expand that with optimisation and sensitivity analysis and uncertainty features that will be part of the tool. You can do the same with CFD (computational fluid dynamics) or Radiance (daylighting), you can do it with simple tools and complex tools.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    First of all it is still a research issue (problem). I think it will add value to simulations but we don't have the proof. If we have it designers will be very likely use it because it enhances the product they are designing, so they can get better products.
    You have to be able to show the designers that the use of those tools produce results better than their design. Actually I think in the future, that there will be very clever designers who say:

well you can do this design alternative, which it is much better in terms of comfort and energy consumption that is cheaper to run. I think that is the way you can convince people. For example, if you are looking for a new computer to buy then you also are comparing performance and power. The solution would be that you can buy something which has better performance than what you have in your brochure. That is the way people make decisions I think.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    I don't think there are technical obstacles. First you have to figure out what kind of optimisation tools is beneficial in the context of sustainable building design. So it is a research issue. Computational optimisation is a technique which is used in many different industries, but the way you do it or design this depends on the nature and type of industry. Automotive industry is completely different from aeronautics, which is different from ship building and complete different from buildings industry. So there are research issues. The first issue actually is what you would like, in the context of building design and operation. Then there will be some development issues, not so many because I think the tools are actually ready. You just need to know which tool is best first. Then you start using the tools so they can suggest you solutions and people can see the benefits. Of course you have to optimise under uncertainty, which is a research issue, so you take uncertainty into account.
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes of course. You are talking about computational optimisation so you have always to combine them.
24. **Which tools would you recommend?**
    I think that modeFrontier is a very good tool.
25. **What features would you like to find in future tools?**
    I think optimisation will be a standard in practice because these optimisation techniques are already available. I think that research in the field of building performance together with mathematicians figure out which optimisation techniques are used best for our circumstances. Then integrate them with existing simulation techniques and tools. So you have to know how to apply them and that is what we have to develop for future tools.

IEA Task 40 Interview with Gregor Henze, University of Colorado, USA

Interviewed: 5 January 2011 (Gregor.Henzeatcoloradodotedu)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building Science – Building Systems Engineering
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Yes, I typically work on controls optimisation. I pick a high performance building design, for example a building with under floor air ventilation, active shading systems, thermally activated building structure. The optimisation problem I am interested in is model predictive control. Asking, what should be the set points, control sequences, and settings of that particular building to operate in an energy optimised fashion?
3. **How many projects or case studies have you performed?**
   15 years of involvement of optimisation of high performance buildings
4. **Approximately, how long does each project or case study take?**
   My current research focus is not on design; my focus is on operation. Some people are interested in the perfect mix of technology and envelope, optimal sizing of system, sub sizing, the tunnelling effect: if you super insulate the shell you might illuminate systems completely. I am currently involved in a USGBC sponsored research project on HVAC control strategies for mixed mode buildings (mixed mode buildings are built to have hybrid ventilation natural and mechanical ventilation and a host of cooling technologies from standard vapour compression cooling to radiant cooling, to chilled beams etc ...) We have investigated a range of possible mixed mode ventilation building and that range from very low degree of technical innovation (sealed buildings, no comfort adaptation, purely mechanically ventilated) to very high technical innovation (active shading, active and manual operable windows, desiccant cooling, no vapour compression).
   We are looking at eight different buildings in our analysis with a scale of mixed mode features. We have made some design assumptions for these buildings and we have bedded the assumptions with best practice and the literature that is out there on current European, North American, Swiss, German, Austrian, Dutch designs. Then we came up with a set of prototypical high performance buildings and once we have those we designed the individual technical

systems in the buildings. Then we asked how we should control such buildings. Most of the buildings exist and some are hypothetical buildings with certain features or a subset of certain features. We make decisions on: window openings behaviour, shading systems, supply water temperature for concrete core condition, supply air temperature set points, chilled water reset schedules, condenser water cooling tower temperature and operation.

5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   For optimisation we mainly focus on model predictive control (MPC).
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   We have developed our own MPC environment that is based on Matlab and uses EnergyPlus. It can be expanded to any other BPS tool program. The next in line we will connect with will be reduced order models, TRNSYS, DOE-2 or ESP-r.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Office and institutional in moderate and cold climate.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   1- Multizone- Full zoning and 2- Reduced zoning.
   2- Multizones for smaller and mixed mode buildings from 2000-5000 square meters and up to three stories. We model proper airflow networks that we set separately and couple it to zones.
   3- Reduced Zones for larger high rise buildings we use zone multipliers or we use per floor a typical approach as a 5 zones modelling with east, west, north, south and core.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   Comfort, HVAC systems operation (advanced controls). We optimise the building controls under a range comfort controls. PMC (ASHRAE 55, EN 15256, ISO 7730). In a building in which the opportunity for adaptation is small we typically use static comfort models as the one of 7730 and ASHRAE 55. In this context we basically set certain PMV limits on each of the zones looking for the PMV variation. Then we set thresholds on what range of PMV is the building allowed to experience during occupied hours and so we use e.g. a limit of +- 0.5 on the PMV limit. The optimizer must find decisions that satisfy for every occupied hour a PMV limit +-0.5.
   The problem that mixed mode buildings have is that there is no agreement yet in the industry neither in Europe nor in North America on whether they are governed by static or adaptive comfort models. So we do both, we bracket the problem by optimizing the building under static comfort models like 7730 and ASHRAE 55. Then we optimize the building using adaptive models using the adaptive portion of it ASHRAE 55-2007 and that would be EN 15256. So you get different results depending on the constraints the optimizer set for control decisions. Control decisions are: window opening, degree of window opening, room air temperatures set points, supply air temperature, supply chilled water temperature for radiant systems.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    Quasi Newton method, sequential quadratic programming, Nelder–Mead method. But I have come to like particles swarm optimization best. We have written our own particles swarm optimization with a range of improvements and modifications for building optimisation.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

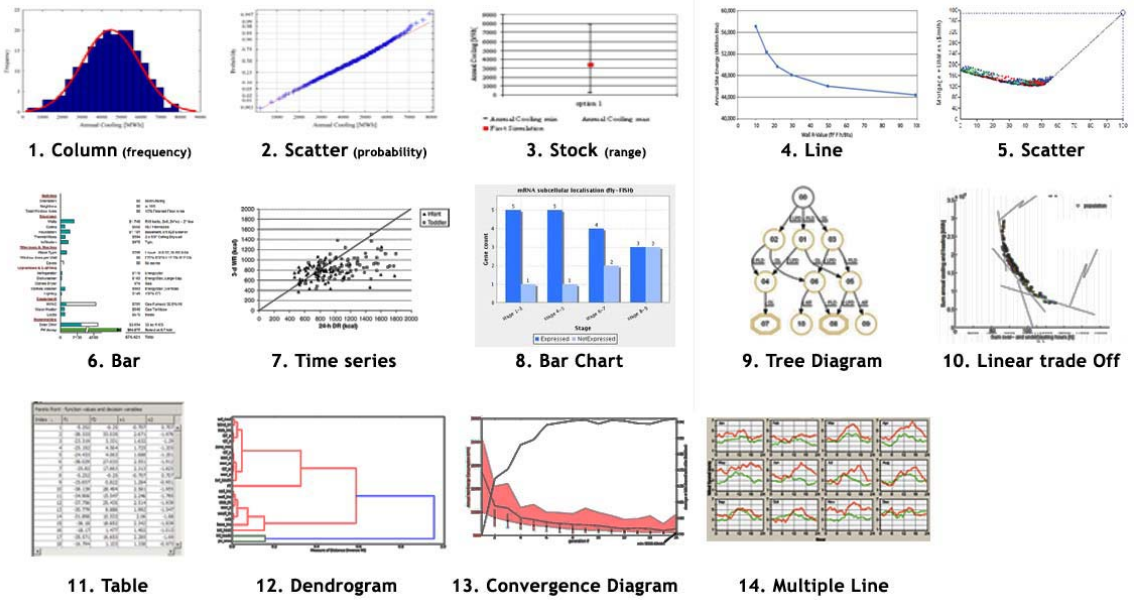
We do explicit optimisation. The optimal results that we get are then extracted as rules.. The idea is that if you optimize let say four decisions for every hour (window opening, supply air temperature, supply water temperature, room air temperature) then I will get 96 decision variable and if I do this for a whole month you end up with a lot of decisions. Now comes the question: If there is any underlying logic or pattern, is there anything that can be learned or gleaned? We call that rule extraction. Our approach is to first use MPC that is very numerically expensive but we extract rules from the results. There are all kind of rules of extraction for example, a multi dimensional interpolation would be one of them, a neural network will be considered as a nonlinear look-up table, fuzzy inference using membership functions. Right now we use different time series approaches for that. All of these are basically post-processing steps we do after the optimisation itself.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Yes. If we have a very complex model and we need to reduce the model we often use fractional factorial analysis to find out which are the most important model parameters. The fractional factorial analysis (FFA) is theoretically a well proven approach to identify the most relevant parameters in a large set of parameters. So we use FFA.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    Typically we use blended cost functions including minimizing energy consumption (site or primary), then we set comfort penalties to avoid unwanted solutions. In addition to comfort penalties we add equipment operation constraints.
    b) **What kind of constraints do you set for optimization?**
    If any zone is out of the range of PMV +- 0.5. Since we are using EnergyPlus we articulate our constraints as penalties because we don't have an analytic representation. We don't have a linear program that we can express since we have a gray box function evaluator called EnergyPlus; so we need to enforce constrains through penalties. That is the only way we can do it.
    c) **What kind of stopping criteria do you set for optimization?**
    Conversions are reached depending on a set of criteria. In the particles swarm optimization it has to do with the Euclidian distance among the different particle and the decision space; if that becomes very small or if the particles stop moving. It is a meta-heuristic optimiser like any genetic or evolutionary algorithm so you are not guaranteed the global optimum so you need a few algorithms specific stopping criteria. The stopping criteria are Euclidian distance among the particles and speed of particles and the function evaluation ceiling of 4000 or 5000.
14. **How do you avoid the insolvable and infeasible solutions space?**
    I didn't try to analyze this deeply but I follow a trial and failure approach. I revise the results and check if they are acceptable.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    unanswered

Output

16. **Do you have GUI for your own optimization tool?**
    No.
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

The results that we get are time series of decisions. In controls what you get temporal sequences of certain decision variables, whether that is supply water temperature or supply air temperature, operation schedules. We use time series plots 7. Figure 5 is famous but we visualize using time series. The solution is to find trends in the plot. It is really hard to analyse the results graphically.



1 Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (Hale), 10 Linear Trade Off (Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot

Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Optimisation, especially when it is discrete optimisation of different technical solutions to buildings.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I expect it to become a required and standard activity. I think the use of optimisation should be during schematic design stages. The model should not be deep with some geometrical zoning simplification. This is what is NREL is working on with BEopt program. They had a standard reference building and they tried all kind of technologies to condition this building.
    I feel like that there is a role of optimisation if you have a detailed design available or when you arrive at the detailed design but I think it is an iterative process.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    I hope that optimisation will play a role NZEB design. There is a role of optimisation early on that provides guidance for which technology applies to which building type to which geometric form of the building should be chosen.

    If we had a tool that allows scalable model complexity where I can start and have a conversation with the client and the architect in the same room and we could use or play on the screen with

certain options and hit a button to optimise. Then, it provides a ranked list of the top three performing technology options. Then, the client for example say I want to pick option 2 ground heat pump so the system picks it and then next step is sizing the ground source heat exchanger. So basically, the model grows and matures when you take it from the conceptual design to the schematic design to the design development and construction documents. Optimisation is always available in the beginning to provide advice on design strategies and technology options and further down you can refine the optimisation question. What kind of exterior wall thermal performance do we need what is the ideal glazing fraction and you run through all those parameters. I think if that is available, an integrated suite of tools, you can initially talk with the client and architect and the engineer at one table and no one is overwhelmed, it doesn't require a lot of optimisation skill, you do discrete optimisation of technology options and later on you do possibly control optimisations deriving control strategies for the building, which is much deeper and more detailed and requires a building specialist. I think there is a phenomenal role of optimisation that we could explore. The opportunities and potential are significant. If we had more optimisation tools available we would have better buildings and it would be a substantial step towards net zero energy buildings.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    Cancelled.

Developers: Shortcomings

22. **What are the major practice obstacles of integrating optimization techniques in NZEB design?**
    - High level of expertise: you need savvy persons for building performance simulation and for optimisation
    - Constraint violation
    - Run time (we wait weeks for results to come in)
    - Model complexity is not scalable
    - Low adaptive resolution of models
    - Limited use for code compliance
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    - Yes, definitely.
24. **Which tools would you recommend?**
    - Genopt with EnergyPlus
25. **What features would you like to find in future tools?**
    - I would like to have a scalable model complexity approach to optimisation, which means in the beginning when I know very little of the building and I am in the programming phase, I would like to use a low-complexity single zone model and I would play with all kind of building technologies. An adaptive tool that allows starting with a very low complexity reduced order model of a building and I explore design decisions and I explore technology options. Once I see the opportunities I decide what I will pick. Then I say I need to go into my schematic design for higher detailed, more zoning, higher fidelity of the model. Now I have to take into account mutual shading for surrounding buildings, I need a more complex model. So a scalable model complexity will be wonderful to have, but it doesn't exist.
    - I see a need for optimisation environment or tool that provides high level guidance at the beginning basically answering some question like: Does is making sense to use BIPV, CHP,

technology options to condition a building (heating, cooling, ventilation). That would consider the site and local climate and the comfort expectations that are regionally different. Some countries are also more stringent than others. I am looking for something like a flight simulator that lets you play with some fundamental technologies types and by pushing a button you can sense what technologies appear to make sense to narrow down your choices. You have a set of fairly high level decision that can be made. Once you use set the shape, orientation, overhangs, envelope performance, U-values you can move to more detailed optimisation. I expect the optimisation to be used to explore relationships and dependencies of design parameters. I think the user group would be any innovative design firm or team that would like to learn about the drivers of the problem.

IEA Task 40 Interview with Lesley Hermann, NREL, USA

Interviewed: 8 April 2011 (LesleydotHerrmannatnrel.gov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   My undergraduate degree is in physics and astronomy and I studied civil engineering for my master's degree.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes, for my current work not so much but for my thesis work definitely yes. The methodology I used for my thesis involved three steps: a parametric analysis, an optimization, and a sensitivity test. The parametric analysis was used to identify the major categories for potential energy savings and to identify what energy design measures (EDMs) were most applicable for the optimization. The sensitivity analysis was used to determine which EDMs had the biggest impact on energy savings.
1. **How many projects or case studies have you performed?**
   There were four building models: There was one office model and one hotel model for two climate zones. The climate zones included a hot humid climate and a severe cold climate.
2. **Approximately, how long does each project or case study take?**
   That is really hard to estimate but probably 3 to 4 months per case.
3. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   Opt-E-Plus with EnergyPlus as the simulation engine.
4. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No, Opt-E-Plus provided all the output that I needed.

Methodology

5. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Office buildings and hotels for hot humid and cold climates.
6. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   The office model had 5 zones per floor with one core and 4 perimeters. The hotel had 9 zones per floor.

7. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Building envelope (exterior wall, roof, windows, windows fins, overhangs, window sizes, window types) and internal gains (infiltration, internal gains, equipment power density) and systems (HVAC efficiencies, daylighting controls).

8. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

   Opt-E-Plus uses a sequential search optimisation algorithm

9. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

   I am not exactly sure but you can ask Nicholas Long.

10. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Yes, after the optimization, I did a sensitivity analysis to identify wich EDMs contributed the most to energy savings. The sensitivity test also identifies how energy savings is related to variable values of each EDM. For example, varying the exterior wall insulation levels from R(SI)-2 to R(SI)-8 showed a parabolic correlation to energy savings and that insulation values over R(SI)- 7 contributed little to energy savings. This shows that for exterior wall insulation, there is a point of diminishing returns.

11. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**

       The objectives were total life cycle cost savings and total site energy savings.

    b) **What kind of constraints do you set for optimization?**

       None just let it run.

    c) **What kind of stopping criteria do you set for optimization?**

       It runs until if finds the design with greatest energy savings. It won't stop when it gets to the "optimal design" which is defined as the design that leads to the greatest energy savings at the lowest cost.

12. **How do you avoid the insolvable solutions space?**

    No.

13. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    Yes, but it was mostly problems with the optimisation tool or my input file. If I did run into problems, I would look in the error files that come out with the simulation to identify where the problems were occurring. If I couldn't figure it out for myself, I would typically go to one of the developers and say "Hey what is going on? Could you help me?" but there wasn't a great error reporting system for the actual optimisation tool. There isn't any report variables that tell you if something is not working the way you have set up your file or optimization.

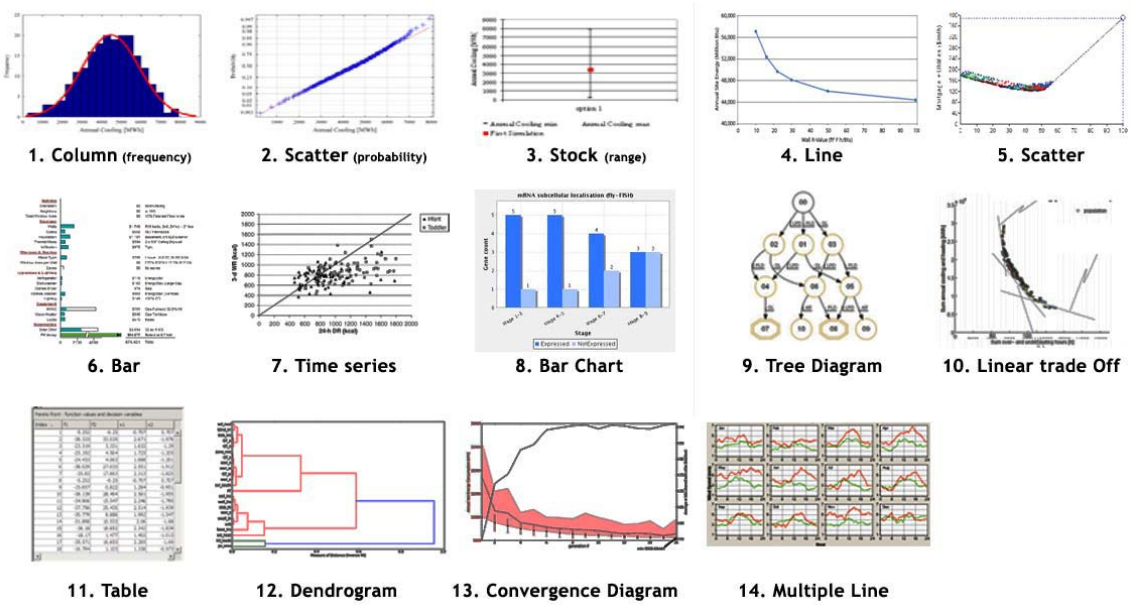
Output

14. **Do you have GUI for your own optimization tool?**

    Yes.

15. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Number 5 is most common for me and number 8 would be helpful to see the starting point or reference case against the other points along the curve in scatter plot number 5. Number 6 would be helpful but I never used it. Number 4 was also important for me. I post processed this information myself in the sensitivity analysis. If I had to rank them I would say 5,8,6 and 4.



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Integration with Design Process

16. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think it's super important because first of all, all building components are integrated. It's a whole building system. You can't just look at the wall insulation or window sizes. Perhaps one of these parameters would save energy in one category but would increase energy in another. Take the window area for example; increasing the window area could lead to more cooling energy due to solar gains, but with more daylight available and the implementation of daylight controls, electric lighting power density could be reduced. Reducing the lighting power may enough energy to outweigh the increase in cooling energy. I think optimisation is the best way to pin point the best building design. It also provides you with alternative building design options that lead to similar energy savings.

17. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think there should be multiple optimisations, at least two. First building massing and orientation should be analyzed, then perhaps the daylighting systems. Then you would have to optimize the envelope and HVAC equipments. Two optimisations may be sufficient, where the first orientation would focus on building massing and the layout of the building and the second optimization would focus on the none-massing components (envelope and HVAC).

18. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    I think it should be anybody in the building design process (architects and engineers... everyone listed above!) and the results of each optimization should be discussed among each group... but that's a whole different problem.

19. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

Optimization tools should have more features. Like I mentioned earlier, they should allow for optimization at different stages of the design, should me more user friendly, and should create nice graphics that present the results in a clear fashion. Perhaps a few cases studies would be helpful to show that performing optimizations actually DO make a difference! Training sessions on how to effectively use the tools would be useful too!

20. **Do you have an idea how can we shift the integration of optimisation more early on in the process?**

Yeah, I think it should be because once you get into a design, then it is hard to go back and change them later. The first thing you should do is orient the building; if you have not position the building in an optimal location, you have already lost a lot of potential for possible passive design features.

Developers: Shortcomings

21. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

- Not having all the components that we have talked about the massing, energy design measures as well as controls all available in one tool that work very neatly. I cannot optimise on schedules in my optimisation tool. So I would like to have a package of all those parameters, possibly broken into categories such as massing, envelope, and systems. Smaller optimization tools within a bigger tool may be more helpful than one gigantic tool!
- Post processing takes a little bit of time
- Building the model was challenging
- Manipulating the output data could have been made easier. Extracting exactly what I wanted was not simple.

22. **Would you use optimization tools if they were integrated unto an energy modelling tool?**

Yes. Sure if it was designed neatly and tidy. You can definitely tell if you are using the building model or the optimisation tool. I see the tool being just visually very clear and adaptive. If I am using optimisation but want the tool to run behind the scenes, I want to be able to click a tab and bring the information to the front, kind of like turning a page.

23. **Which tools would you recommend?**

I think BeOpt may be set up in a more user friendly way, but it doesn't provide the capability (as far as I know) to optimize large commercial buildings.

24. **What features would you like to find in future tools?**

- The comfort report and better daylighting analysis (lighting levels)
- Indoor air quality
- More graphing options
- Error output
- I would like to have visualization of multiple objectives. I think a 3D plot would be helpful if you wanted to show energy, cost, and carbon savings. Perhaps color could show results for occupancy comfort.

IEA Task 40 Interview with Peter-Jan Hoes, Tech. Univ. Eindhoven, Netherlands

Interviewed: 27 May 2011 (p.hoesattue.nl)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building physics/building simulation
2. **How do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   We want to optimize the performance of building design of NZEBs (reduce energy demand and improve comfort) by optimizing the building design including the building systems. To minimize the possible variables in the optimization process, first we use sensitivity analysis (e.g. Monte Carlo with regression analysis, Morris analysis) to identify the most influential parameters. Next, we use these parameters in the optimization process.
3. **How many projects or case studies have you performed?**
   Two or three cases.
4. **Approximately, how long does each project or case study take?**
   This is difficult to answer. I did the optimization of some case studies as part of my PhD research project, which is still ongoing. Regarding computational time for each run, maybe 2-3 days per run.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   In our group we use modeFRONTIER and Matlab (with the optimization toolbox). We use both programs for single- and multi-objective optimisation. The programs can be coupled to basically any program, but we use it for ESP-r, TRNSYS and Radiance.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Mainly residential buildings in European climates.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   In the case study for my PhD project, five zones.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   In my case study I optimized the thermal mass of every specific zone and the window size.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Mainly genetic algorithms. We use NSGA-II, which is a well known algorithm for multi-objective optimisation. But we use also the 'in-house algorithm' of modeFrontier, it is called Multi-Objective Genetic Algorithm (MOGA). Well we are experimenting which algorithm works best. We use genetic algorithms because they give you a very wide range of solutions and are not likely to get stuck in a local optimum.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    ModeFrontier can use neural networks to create meta-models during the optimization run. These meta-models are used to generate extra design evaluation, and will speed up the optimization process.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Yes, normally we perform a sensitivity analysis to see what effects are influencing our design or not.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    The reduction of heating energy demand and weighted overheating hours (based on PPD and PMV).

    b) **What kind of constraints do you set for optimization?**

    Constraints on the maximum number of weighted overheating hours. So for example during a period of one year only 200 hours are allowed.

    c) **What kind of stopping criteria do you set for optimization?**

    Maximum number of generations.

14. **How do you avoid the insolvable solutions space?**

    I guess this depends on you optimization problem.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    I use genetic algorithms for that because it doesn't collapse.

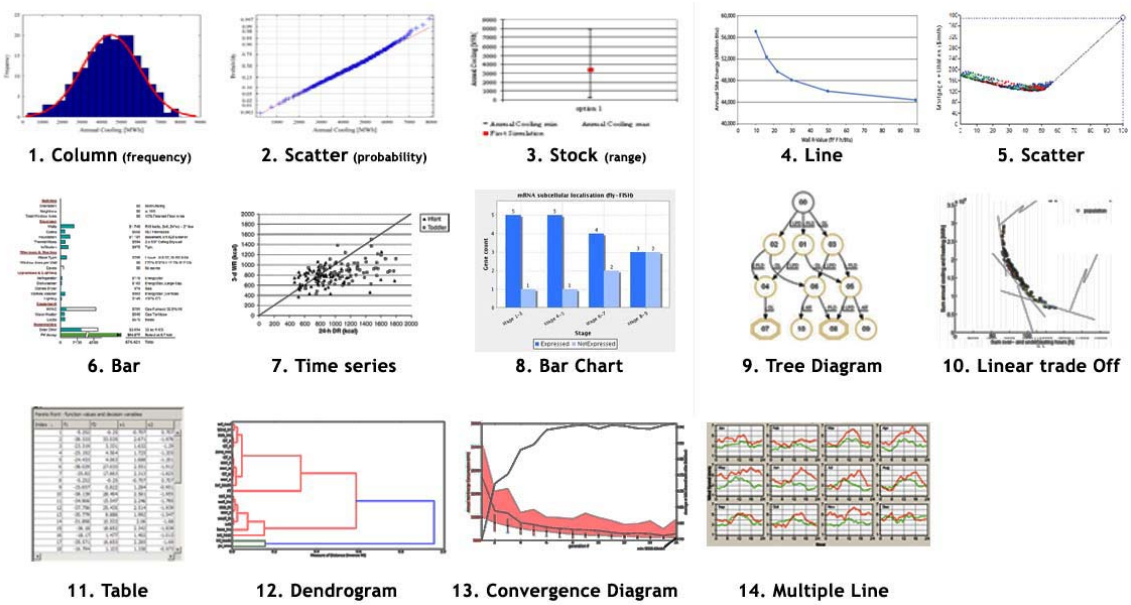
Output

16. **Do you have GUI for your own optimization tool?**

    ModeFrontier has a nice GUI with many graphical outputs and statistics on it. But I am using my own Matlab codes because it gives me flexibility and allows me to present the results exactly the way I want.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    1,2, 5, 6, 8, 10 and 11.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    There is great opportunity to integrate optimisation for most NZEB. For NZEB which rely on low energy systems and passive concept, it is just too complex to optimize the design without optimization tools. So I think it is necessary especially for innovative and integrated designs.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I think you can use it during the whole design process; however you should have different tools (with different resolutions) for every phase.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    It depends on the tool. It would be best if someone uses it who knows the algorithms. During early design stages you can have maybe simple tools for architects without getting into the algorithms.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    Actually optimisation helps the decision making very much. Using multi-objective optimisation for example, you will get Pareto Fronts with different solutions. You could pick a variety of Pareto solutions and show it the design team. I think this is how optimisation can be integrated in the design process very well.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Computing time
    - Time for data analysis and post processing
    - Not properly integrated in simulation tools yet

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes
24. **Which tools would you recommend?**
    modeFrontier, because it has a GUI, it easy to use and to couple to EnergyPlus, ESP-r , TRNSYS, etc.
25. **What features would you like to find in future tools?**
    More efficient algorithms
    Integration of simulation and optimisation tools

IEA Task 40 Interview with Christina Hopfe, Cardiff University

Interviewed: 27 May 2011 (hopfeCatcardiff.ac.uk)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   I studied civil engineering, with major in computer science in Germany. I did my PhD in the building physics department at TU/e, The Netherlands. Currently, I am a Lecturer in Civil Engineering/ Sustainable Engineering in the UK.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes. I did a major part of my PhD research on optimisation and optimisation studies using multi and single optimisation for building performance simulation. I teach basic principles of optimization and uncertainty analysis to my fourth year students.
   I am still doing optimisation at work but this is quite focused on single objective design problems. For instance, in a project led by the BRE, we collaborated with the entire design team: During the design process, we had to come up with different concepts optimising the building management system, the energy consumption of the building and improving the comfort. For that reason, we set up different scenarios for instance, changing the window to wall ratio or different scenarios on occupancy behaviour etc. We ran 100 simulation sets and checked what kind of uncertainty there is and what can be optimized in terms of the entered parameters (sort of conceptual design optimisation). This particular example eventually led to an improved window specification.
3. **How many case studies have you performed?**
   In my PhD research I conducted a number of cases and now at Cardiff University I am involved in a number of projects. One project investigates climate robustness. That means that we check the effect of different climates on thermal/ acoustic comfort.
   Another example is a research project dedicated to social housing and passive house design where we just used simple Excel spread sheets in order to optimize the design layout of the buildings.
   In total, probably about 15 projects.
4. **Approximately, how long does each case study take?**

6 months up to 2 years.

5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   Well, for simple optimisation studies we just use excel because some of the simulation tools are steady-state tools. In more complex studies, including multi-optimization using dynamic simulation, I used Genopt and Topgui. Nowadays I rarely use them due to the fact that it implies lots of effort and is something that cannot be used during a design team meeting, providing you with immediate results.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, I was using Topgui and I have been working with Michael Emmerich, assistant professor at Leiden University. He developed for instance SMS-EMOA and we implemented a prototype comparing non-dominated sorting genetic algorithm (NSGA) to compare the stochastic evolutionary algorithm. There was some programming involved because we had to couple this prototype with uncertainty and sensitivity analysis – in order to minimize the simulation time steps and duration, we used Meta-models. The algorithm itself was programmed in Java and I used Java to adapt it to our performance simulation and Matlab as pre- and post processor.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Domestic buildings, commercial buildings, single houses, multi family houses; new build and retrofit.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   It depends often on the client, time and budget involved in the project. Very often an exemplary single zone is taken in order to show possible effect and consequences
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   In the past (as a PhD student) I often focused on the building geometry. At present: climate (future and micro), renewable systems, internal gains, lighting and occupancy profiles
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    I used both; I started with deterministic optimisation using Hooke- Jeeves for single objective optimisation in Topgui. This had the advantage of a fast convergence to local optima; however it might not find the global optimum.
    I also used evolutionary algorithms. They take longer but it enables you to find surprises in optimisation. I used NSGA II and SMS-EMOA.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Yes, I started solely with uncertainty and sensitivity analysis.
    I also combined sensitivity analysis and uncertainly analysis with the optimisation.

Under which setting you run you optimization what is your methodology?

a) **What kind of objectives do you set for optimization?**

Energy consumption (annual and peak loads) as well as thermal comfort (GTO, WOH, WUH)

b) **What kind of constraints do you set for optimization?**

design criteria, e.g. geometry of the building, window to wall ratio etc

c) What kind of stopping criteria do you set for optimization?

Maximum number of generations.

13. How do you avoid the insolvable solutions space?

I find deceptive and invisible solution spaces to be less of an issue for building simulation. Optimal landscapes are flat (meaning that minor variations in design parameters do not yield large simulation differences)

14. How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)

n/a

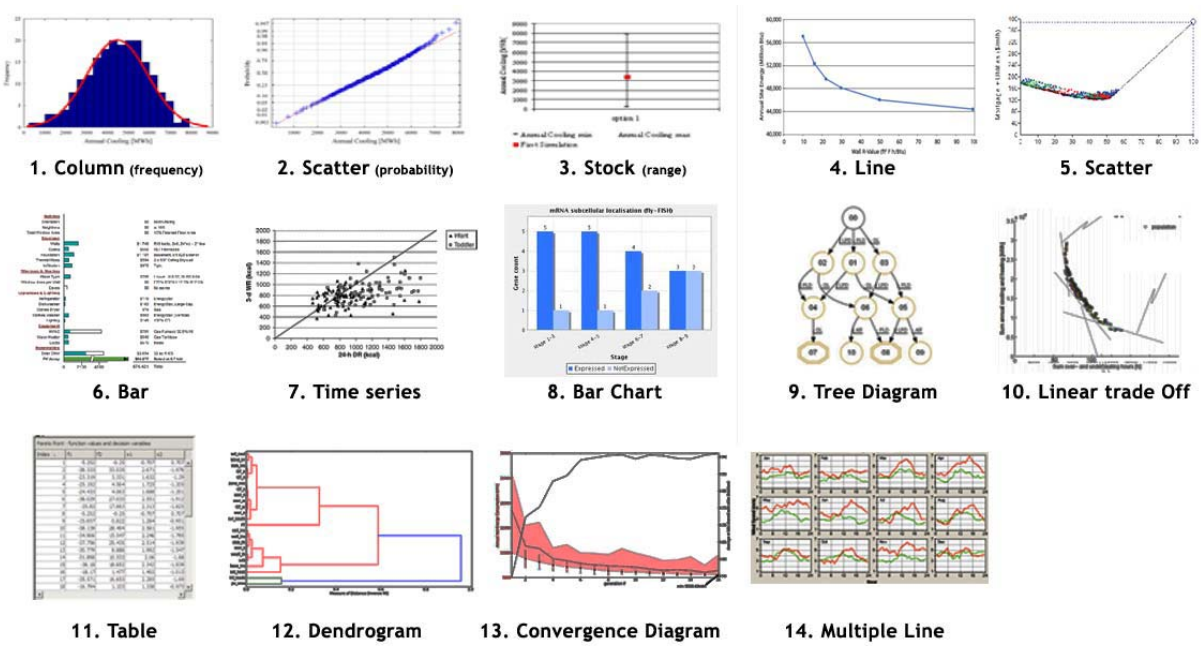
Output

15. Do you have GUI for your own optimization tool?

No. We basically used gnuplot command-line driven graphing utility, and/or Excel and Matlab for post-processing.

16. Which kind of output analysis visualisation did you do using optimisation tools? (1-14)

My favourite graphic is number 10 as it represents optimization including the uncertainty analysis. However, in design projects, the most favourite to clients is a graphic comparable to number 8- showing interactively by scrolling a number of parameters the effect on the outcome- which is ideal in steady-state simulation.



1 Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (© Elaine Hale), 10 Linear Trade Off (©Christina Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot

Integration with Design Process

17. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    There is a lot of opportunity – still however, in "real" life as opposed to a research environment, simulation time is a big issue and optimization in BPS is not yet fast and flexible in terms of design adaptations and the resultant visualization.
18. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    From my point of view it fits perfectly in both, conceptual and detailed design stage.
    In conceptual design stage, for comparison of different options and design variation, a graphic such as number 8 is very beneficial.
    In detailed design, different parameters and constraint will be of importance, the model will be more complex, probably the amount of parameters higher, therefore simulation time longer.
19. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    An experienced person in simulation preferably a building physicist or mechanical engineer or similar.
20. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    Building performance simulation is a decision making support tool and optimisation can be added in order to make it more an informed decision making tool. If you have optimisation as an extension to a tool and you can use it while having graphical outcome charts to present like in the graphs from 1 to 14, comparable to an integrated performance view

Developers: Shortcomings

21. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - possibly computing time (but this is not a long term issue due to improving computing power)
    - Problem definition as well boundary or constraints
    - Limitation of number design variables
    - Result interpretation and consumer acceptance
22. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes
23. **Which tools would you recommend?**
    Genopt and Topgui
    What features would you like to find in future tools?
    Optimization should integrate uncertainty analysis and should be possible anytime and anywhere, e.g. as an I-Phone application.
    During the optimization process, swopping in between different tools, therefore being able to optimize only 2 or even 20 performance aspects.

IEA Task 40 Interview with Dirk Jacob, Fraunhofer ISE, Germany

Interviewed: 26 September 2011 (dirk.jacobatise.fraunhofer.de)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   I got physics degree from a German university (Diplom-Physiker)
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   I am mainly dealing with building operation optimization (of existing buildings). Sometimes this is called continuous commissioning or ongoing commissioning or energy audits. I usually use optimization in a mathematical sense. That means I have an objective function (some building simulation) e.g. yearly energy consumption, which I minimize with an optimization method (I usually use PSO and therefore call it optimization heuristics).
3. **How many projects or case studies have you performed?**
   Optimization Case studies: Many if you count all automatic optimization cases it is probably > 30 million. Projects: probably > 20. I did studies on optimisation convergence and for that I had to do a lot of optimisations for each case I looked at and that was millions of optimizations for every case. By convergence I mean, that the optimization reached the true optimum.
4. **Approximately, how long does each case study take?**
   Very different, between 10 min. and 6 month
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   In order of importance for me: R (http://www.r-project.org/) (An open source statistical programming language widely used in social sciences and statistics), GenOpt, Excel, Matlab objective function: R, Modelica (Dymola), IDA-ICE, TRNSYS, Excel, Matlab.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   I implemented several variations of Particles Swarm Optimisation (PSO) in R.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   All you mentioned, and other problems, mostly in Germany.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Single and multi-zone models (although more often single zone, depending on the question)
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

Design: orientation, window sizes, wall-thicknesses, pump and pipe sizes... control: MPC-questions, controller-tuning, stochastic optimization with uncertain occupant behaviour. I also worked on solar collectors and I had some co-working projects with PV collectors and combined PV and solar collectors and combined heat and power generation (CHP).

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

I use both. Deterministic (gradient-based) BFGS for example if it works it usually is very quick and accurate. BFGS method is a quasi-Newton method (also known as a variable metric algorithm), specifically that published simultaneously in 1970 by Broyden, Fletcher, Goldfarb and Shanno. This uses function values and gradients to build up a picture of the surface to be optimized.
I hardly ever used genetic algorithms but I very successfully used PSO a lot. I would count PSO as a stochastic optimisation method like genetic algorithms and it is a bit similar to evolutionary methods.
I use deterministic algorithms because it works very quick and very accurate. I used evolutionary algorithms long times ago a little bit in Matlab and it seemed to work slower for these problems than other algorithms, so we focused on PSO for building problems.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

No (other post-processing techniques)

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

I personally haven't used sensitivity analysis a lot but a colleague is helping me with that.

13. **Under which setting you run you optimization what is your methodology?**

a) What kind of objectives do you set for optimization?

It is almost impossible to give a general answer here. Many times I use a setting like the following.
Objective: cost (energy + comfort (penalty)) optimization parameters/variables: control signals

b) What kind of constraints do you set for optimization?

E.g. control signals between 0 and 1

c) What kind of stopping criteria do you set for optimization?

I usually use PSO and raise the number of particles and generations as long as the results are changing. Or I do detailed convergence analysis.

14. **How do you avoid the insolvable solutions space?**

Usually I set my constraints to avoid this and make sure the simulations work for all possibilities (which are not always easy).

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

I try to monitor the simulation output for that and sometimes implement automatic restarts for failed simulations (due to external interruptions) (difficult task, very problem and program specific).

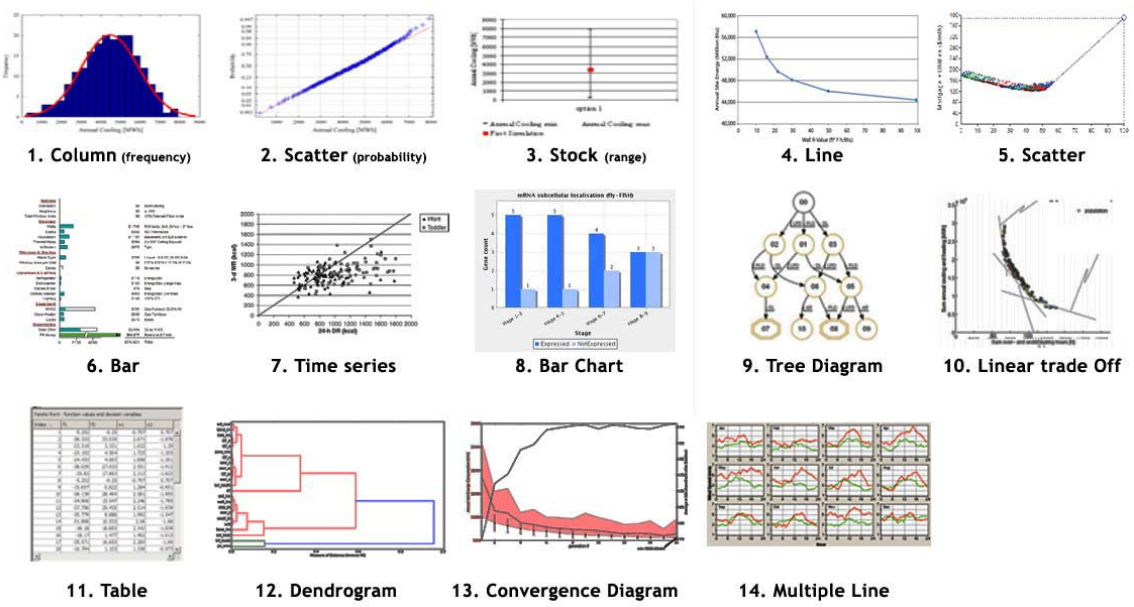
Output

16. **Do you have GUI for your own optimization tool?**

No (I don't need it)

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Many different plots, automatic analysis, ..., (always problem specific) 1.-5., 8., 11., 13., 14.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    It is a great opportunity, but it needs people who know how to do it (not enough around). I see a lot opportunities in controls issues like we have been doing in the last two years. Also I see that it could give answers to questions like what would be the right size of something or the right thickness of insulation or the best window type. A lot of these questions are answered by architects saying: I like it based on how it looks. But it is also possible to look at this as an optimisation problem. So if people would be doing more optimisation and would talk more to each other, it is possible to find better solutions for many problems. But as I said there are not enough people to do it.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    Early and middle stages of design and later for the optimization of operation (or control optimization)

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    Everybody who knows how to do it! --> Most likely: simulation consultant, mech. eng., ...

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    I first use optimisation when I was in a design office 5 years ago. It was not easy but it was possible and successful. I think there is a big need for building information modelling (BIM) that would probably help a lot if that works for a lot of programs and people. There would be a chance if there is more automatic procedures for building models and automatic optimisation building tools that are coupled to modelling programs. But the first thing is to have more people to learn it and do it. Because it is very dangerous if you don't know much about it and do something automatic you won't notice some stupid answers some tools might give you because

you did something wrong. That is even worse than not trying to optimise things. So it is really very important that more people learn how to do optimisations.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

It is very important that people recognize that they have to watch convergence, so they don't have none convergent answers. If an optimisation method is running but not long enough it is not finding the actual optimal point and then it is not converged. This is really something that needs to be addressed, that convergence is very important for optimisation. The other issue I see in the building sector, especially for NZEBs is, that it is absolutely necessary to think about stochastic influences or uncertainty in these buildings, because They are so much occupant driven and it is not valid anymore to forget the influence of occupants and say I know the parameters for ventilation or occupancy, for lighting etc. These are not certain and if you do optimisations with some parameter set and get some optimal value this could be totally different if you change some of those parameters. It is very important to take into account all these uncertainties. I also list the following as part of the obstacles:

- Models are expensive, because they are still a lot manual labor!
- Models are specific, hard to change, hard to handle, hard to maintain.
- Building Information are hard to get (expensive) BIM should be more Commonly used and expanded to building systems.
- Models need to be more easy to use (avoid instabilities ...)
- Models need to be quicker, ready for parallelization
- Optimization methods need to be easier to be applied.
- Optimization methods need to be ready for parallel computing.

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

Yes, although I prefer to be able to tune and change the optimisation-methods

24. **Which tools would you recommend?**

I usually say, it is best to use what you know best (for me see above)

25. **What features would you like to find in future tools?**

Parallelization for broad application and automatic features. In fact computers can't get much faster anymore by increasing the CPU clock time. This is impossible by physical laws and what they actually do is to have more kernels in each computer. So we need to have optimisation tools that can use all these kernels and we also need modelling methods that use many kernels. That is in my opinion the direction of research that should be taken for optimisation and building modelling.

Regarding automation we need better building information modelling. If the designers make a BIM model and you have simulation programs that can use this information it would be much easier to come up with building models. You wouldn't need to go to the drawings and take out the data out by hand and so on. It would be automatic. The needed tool would allow designing buildings and simulating them automatically without manually transferring data.

IEA Task 40 Interview with Michael Kummert, Polytechnique Montréal, Canada

Interviewed: 09 June 2001 (michael.kummertatpolymtl.ca)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Mechanical engineering in buildings
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes. Well it started with a manual process. It's like a trial and error. It's also related to the work of a design team rather than I single person. We will see that later in the detailed questions but I am mostly using one program which is TRNSYS and I am using some optimisation engine like GenOpt. But it is not a purely mathematical process. I don't see optimisation as a purely mathematical process but rather a methodology followed by the whole team so it is mostly a human process rather than just an algorithm.
   I think if you do simulation work for designing buildings or systems there is always some degree of optimisation.
3. **How many projects or case studies have you performed?**
   I have only worked on a few real projects that have been built; the rest was research work or early stage real projects. The one net-zero project that was built and is currently being monitored is the "Abondance triplex" in Montreal. I was involved in some design charettes at the beginning of the project and we did apply Genopt to TRNSYS simulations. The rest of the design (to which I did not participate) involved many simulations and the search for the best performance/cost ratio, but again the "optimisation" was very much team work rather than computers crunching numbers.). More recently I have been involved in design simulations for a net-zero (or even carbon neutral) community. At the community level the scope is so wide that I don't see how you could apply optimisation algorithms to detailed models. You could apply optimisation algorithms to early stage design tools but that is not typically what I am asked to do in a project.
4. **Approximately, how long does each case study take?**
   The project optimisation was for the building envelope and HVAC systems but not for geometry. So my specialisation is systems and the thing we were doing for that project pr particular case

was to compare different options, how for you go in optimisation on passive solar gain versus optimised systems versus just adding more PV to make it in net zero.
So in that case the constraint was net zero. It was a real project where we wanted to reach that target and it was the cheapest or least expensive way to reach net zero. That was what we optimised but again it was more a sort of manual process. We did some Genopt optimisation but it is not the main part of project I would say.
Then other project that were mainly simulation based and really built it, was more a like simulation studies. Sometimes in that case there are some studies that was done with Genopt in a more sort of systematic was but I have been involved in real 4-5 real projects and these ones I have never implemented the results of GenOpt. I have never seen actually that in my life. It is always the design teams' decision and it has little to do with optimisation as an algorithm thing.
A very simple example that happened recently in a real-life project is the optimum tilt angle and slope of solar collectors for an SDHW application. Students were involved and they ran many TRNSYS simulations to see how to fit collectors on a roof with some shading and an unfavourable shape. They did find an "optimum". Then a contractor was invited to visit the site to provide a quote. He said "if you line up all collectors towards the east it will cost much less because I can save a lot on piping and installation". We did use simulations to validate the "East" option and select a suitable tilt angle – so I am certainly not saying that simulation is not useful. But what I am saying is that it is useless to apply powerful optimisation algorithms if your model (be it a detailed TRNSYS-like model or an "early stage" model) ignores some important parameters.
It depends. If you work for a paper or report then for example in the case of hybrid ground source heat pump system then you try to use GenOpt to optimise the solar collectors' area versus the borehole or some things like that. You do that at least.
It could be a few weeks, but if it is a real project it can take years. From the first meeting with the design team until all design decisions are taken and the project construction starts you do that in years. So in that case simulation time is not always a big issue although perhaps one problem is if you want more detail the simulation time will be very long and the rest of the team will not wait for two weeks.
Two weeks seems fine to me, but if we are talking about a real project then you have to meet the whole team and then you say I will get back to you in two weeks with the results. This will be reasonable but there must be some main questions that need to be answered faster than that. I would not get involved in a study if I know that the running time is more than a weeks. In this sense, I would say no. I won't do that because I think it is not important, like the rest of the discussions and the analysis and the interaction with the rest of the team. So if you are waiting for more than a week waiting the computer to crunch some numbers I personally won't do that. But we are talking on running g time. If we talk on the time we set up for simulation of course then it will be much larger. Normally in the design problems I don't start from scratch I have a common problem that has a model already. Then I will do some adaptation and then some optimisation. Normally on sub-set it works. In real life you run one or two parameters we don't look at everything in the same time. So I will tend to look to some parameters and once you look a decision you can look at optimising that decision.

5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**

I use TRNSYS for simulation and I use Genopt for optimisation, but I use Matlab a lot for meta-processing and reporting and post processing, sometimes for pre-processing as well.

6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   For NZEB it is only residential. The real project was in Canada. For optimisation I worked on offices and special types of buildings such as data centres for example. Those were some design optimisation studies, but that was not net zero on the HVAC systems. Also I do sometimes optimisation for some solar thermal systems or ground source heating systems. In some cases I was also involved in later stages of the design so it was more about the system operation in the building and there was retrofit case. Most the buildings were in Canada, except the data centre was in the UK.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Multiple-zone, but I try to keep them a small number. For residential I might have two-three zones per unit. If it's a community-scale model we would likely use building archetypes and several units within each zones.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   Mainly HVAC systems not because I think that this is the most important variable. But just because this is my expertise so others are busy with other aspects. Also when I talk about HVAC systems I include solar systems, PV and advanced controls is part of that. I don't see those as spate things.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    I did not have much time fizzling with the algorithms. I used the simplest evolutionary algorithm in Genopt that you can find. I use Genopt because it is convenient and I couple it with TRNSYS. The first algorithm I normally use is trial and error and parametric runs. This is of course very basic but that is the first task you normally do. So you make some attempts and that give you a sort of rough idea of the scope and perhaps the solution space. Then you can go and refine certain things. But this is influenced by how you set up the simulation. I normally build the simulation TRNSYS and then put Genopt on top of it and just run it just like that. Already while building the model you run many simulations, and maybe you do a few parametric runs. So this is part of a rough solution space refinement. Then you apply the actual algorithm to refine the solution space. But you have to do that in advance before applying the algorithms otherwise you simulation will crash. So you need to explore it manually first.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Sensitivity yes but in a manual process. Ideally, I would like to have sensitivity analysis and uncertainty analysis built in the simulation tool.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    Energy performance and cost (capital + operation).

b) What kind of constraints do you set for optimization?

The way we did it was to consider the net zero energy objectives as a constraint and minimising basically the cost. Since my role in the team was running detailed model on the HVAC systems and optimizing that with the controls etc... It was a sub task of the other problems excluding the geometry and envelope. Also comfort was considered as a constraint.

c) What kind of stopping criteria do you set for optimization?

Nothing.

14. **How do you avoid the insolvable solutions space?**

I try to reduce the risk by exploring the solution space manually in advance. (see answer of question 10)

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

In the beginning I do many parametric runs aiming to explore everything. After that I will run Genopt and cross my fingers....

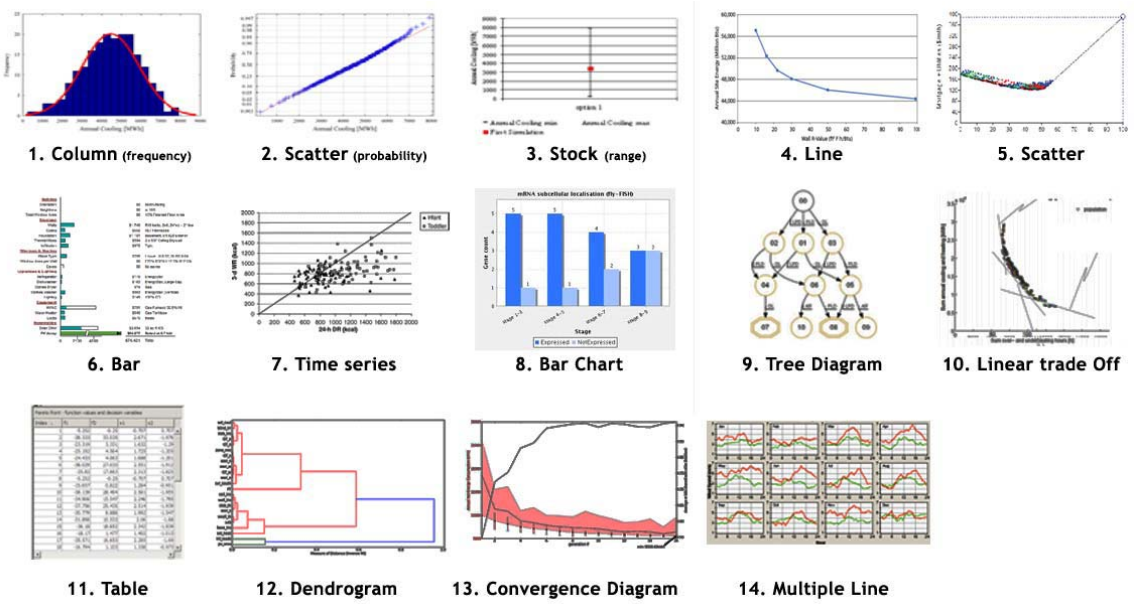
Output

16. **Do you have GUI for your own optimization tool?**

No, but I have some scripts and functions developed in Matlab but it is not a GUI.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Mainly time series like number seven this is to make sure that the simulation is running well but the output I would like to see would be the scatter number 5 and also 8 for comparison.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

For the optimisation of the design is the responsibility of the whole team. As an engineer I see that engineers have to come up with technical options that are comparable and meet the heating and cooling requirements and ventilation etc... But the whole the design cannot be

optimized by an engineer that is running simulations it is a team effort. So I do see potential for optimisation but on all design levels. The key is to keep the complexity within reason in order to have reasonable computational time as the effort to analyse the results. Perhaps there is a need for other tool at earlier stages as simpler levels. Perhaps I would like to see simple tool with graphical interfaces that can make you compare some design idea during early design stages. After that the optimisation of detailed design and system can be done with higher level optimisation tools. I believe that those tools have to be integrated in the process but they can never replace the iterative process of the design team. That is here not about software but about communication between human beings.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    Like I said before I think at all stages, but there must be there fast and easy tools available for earlier levels. However, I am the guy who designs the detailed systems and intervenes in the later design stages. I most probably have an input at later stages.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    The way I have done it, is that there was always an expert. I think it would be nice to get all people involved in design to use building performance simulation – and perhaps optimisation – but it's just a dream. . We have talked a lot that architect would use BPS tools but it seems that it still has to happen. The nature of optimisation as a mathematical algorithm done through software should be used by engineers and experts in their fields. There will always be an expert in the design team, because you always need someone to get the results and more importantly to explain them. If you have a nice piece of software that gives you nice output plots, charts and graphs for example for an multi-objective optimisation you need someone to explain that for the team. I don't think that the software will explain that for you. Perhaps this is because of the complexity of the systems and difficulty to interpret the building behaviour. There is a question also of the level of detail. I think at the level of early stage if you are having a broad idea of how the system can behave I think it should be possible to use an optimisation tool sort of directly. But if you are going to use it during later stages with high level of detail in that case the systems will to complex to be optimised by clicking on a button in software.. So my option is influenced by the level of detail I am used to work at.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    I think optimisation using detailed models can realistically be applied to sub-problems by experts in the corresponding field. It is then their job to explain the results to the design team and to feed information from the team back into the software they are using. Broad-scope optimisation tools based on simple models can be used by the design team as a whole but I think it will be hard to replace the human part in design decisions.

    Can you answer this question in a couple of sentences please?

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

    - The subjective nature of the design process. For me the design process is a human process done by a team and many decisions are subjective. This is the way the design process goes to limit the complexity you need to make some choices at some point otherwise you will never make progress and never build a building.

- The complexity of optimisation problem. There the question of what do you want to optimise. You are not only optimising parameters but also configurations. The level of simulation. So defining the problem and translate that to the simulation and optimisation tool. That changes depending on the project.
- The complexity of changing any configuration. Most existing tools allow to change parameters easily but re-configuring a system is another story.
- Also the problem of cost. You can't put cost for all design options we can't find cost information and have the cost change associated with every design modification or change
- Combining the output of different optimisation tools and sharing the models.

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes, if it is fully integrated in one package. With all the caveats mentioned before…
24. **Which tools would you recommend?**
    I think there is a tool for everyone depending on what you do. Different people use different tools and it also depends on the design question you are trying to answer. The Genopt-TRNSYS combination works well for me but it would certainly not be the best choice for other. There is a GUI for using Genopt in TRNSYS called TRNOPT. I think this is a step in a right direction, but I can't say I would recommend that combination to everyone or for all design questions.
25. **What features would you like to find in future tools?**
    Being able to compare different design configurations at the same time and not only design parameters. Have also maybe one integrated tool that can take you to all the stages from defining the simulation model, some variant you want to compare and then running the optimisation for you and presenting the results.

IEA Task 40 Interview with Nicholas Long, NREL, USA

Interviewed: 8 April 2011 (nicholas.longatnreldotgov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   My background is electrical engineering. I have been working for nine years in buildings sciences and because of that I have been doing a lot of programming. At NREL I do software development for optimisation purposes.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Until, I started working at NREL I never considered optimisation for high performance buildings. Now, I am a software developer for tools that can help designers.
3. **So what tools did you develop?**
   The first tool that I wrote is called Opt-E-Plus. It was the first NREL tool that was used to do optimisation for commercial buildings. It uses a middle-ware that we use called EnergyPlus XML pre-processor. So Opt-E-Plus will manage the files and simulations for our super computers. Then it will write our XML files that will be then converted to EnergyPlus that would be run and analyze. Then the loop will start and you view the optimisation results.
4. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, using Delphi/Pascal. The algorithms were similar to what was done for residential (BEopt), except that we had different constraints and different objective functions that we cared about. The bi-objective gradient search algorithm was similar that marched through iterations and take the steepest slope to create the Pareto Front.

Methodology

5. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Commercial building for USA climates (i.e. ASHRAE 1A through ASHRAE 8). Focused mainly on Retail, Office, Schools, Grocery, Warehouse, Small Hotels, and Dormitory.
6. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   It is a multizone model and there are several ways to create geometry. You have templates such as T-shape, H-shape, U-shape, rectangle, and courtyard. For each of those you can have single zones per floor or you can have perimeter core per floor. So for a T-shape building with a perimeter core you get 9 zones per floor. For an H-shape it gets complicated and will have more

than 9 zones. If you look at the EnergyPlus Example File Generator it will show you the same ones that are available. OpenStudio is the other method to import geometry. We are able to import geometry from those files so you can do a custom format.

7. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   There are about 100 different categories that we can set. Everything from location, floor-floor height, WWR on all of the facades (or each cardinal directory), roofs, walls, doors, refrigeration systems, HVAC systems, from ventilation rates to COP efficiencies, PV systems, service water heating and its efficiencies. I know I am missing several of them but there are about 100 categories. For each of those you can have as many inputs as you want. So you can have ten walls for instance that you would select, ten exterior roofs, and 15 refrigeration systems. So the combinatorial adds up quickly. Then the optimisation will pair it down. Typically on a ratio of 100,000:1 so you would typically look at a good parameter space of a trillion different combinations and we would pare down to about 100,000.

8. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

   We call it deterministic. It's called the sequential search algorithm. It is a gradient type algorithm that would look at steepest slope.

9. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

   No.

10. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Because of how the algorithm is designed, the first iteration of the optimisation is the one-off parametric analysis of all the options selected.

11. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

       The algorithm is bi-objective and can be set by the user. Typically we have cost on one axis and energy on the other axis. The cost is typically total life cycle cost because that is what most building decision makers deem as most important. Other options are energy cost, capital cost, demand cost, etc. The economic input also requires discount rate (real/nominal), inflation rates for gas and electricity, life cycle period, etc. The other axis is typically net site energy savings. Other options include source energy savings, by end use, district heating/cooling, etc. You can do energy versus energy, or gas cost versus electricity cost.

    b) **What about comfort?**

       No, the optimisation does not address comfort. That would be a third dimension that we have always wanted to add to make it tri-objective.

    c) **What kind of constraints do you set for optimization?**

       We don't set any constraints we just let it go.

    d) **What kind of stopping criteria do you set for optimization?**

       Stopping criteria was when you start going backwards? So once the Pareto front has two inflection points, the optimization is over.

12. **How do you avoid the insolvable solutions space?**

    We didn't, we assumed than everything is solvable.

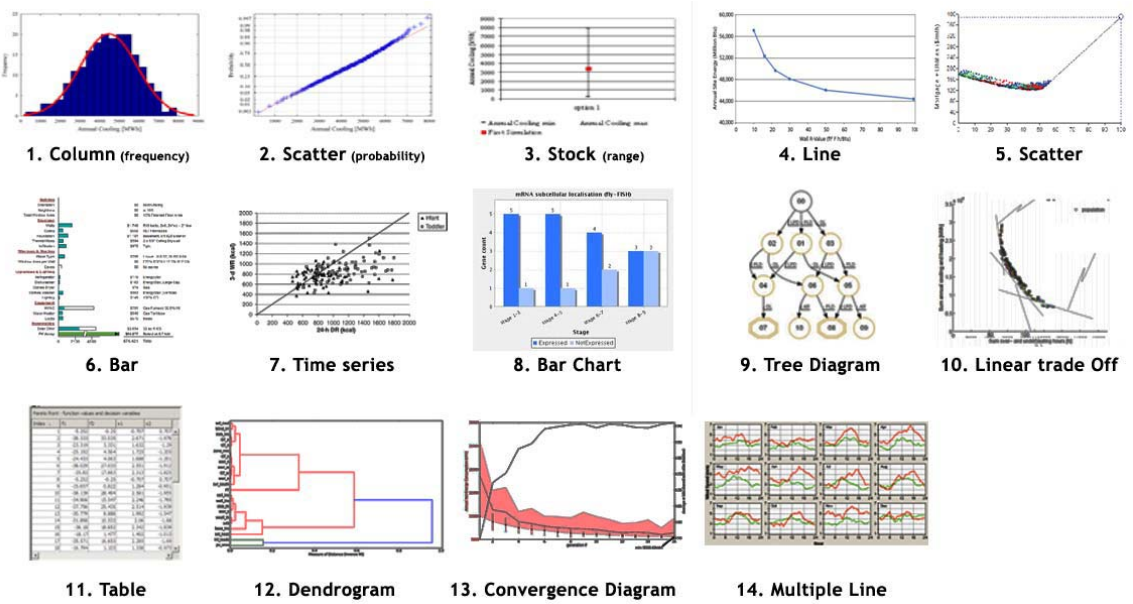
13. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    This was handled in the pre-processor. The pre-processor managed the inputs so you wouldn't have anything that doesn't make sense. For instance, walls or window that extends the

boundary of a subsurface, the pre-processor would send a message out and then reduce the size to fill the whole subsurface.

Output

14. **Do you have GUI for your own optimization tool?**
    Yes, Opt-E-Plus interface.
15. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    We chose 5 because it already had applications in buildings. We do Figure 8 for end use bar charts and 9 for parameter space navigation.



1 Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (Hale), 10 Linear Trade Off (Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot

Integration with Design Process

16. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    The first challenge is that you have to integrate energy modelling early on. Very few design teams do analysis in the early phase. One example where they did was an architectural firm doing site analysis and energy modelling early on trying to determine the best WWR, orientation, rough skin to roof ratio, skin to volume. In general, the design teams just need to give them a tool that they can be use early on and preferably the resources that they need to run the analysis (such as “the cloud” or supercomputers)
17. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    In the whole design process I would like to see actually a new job coming up in the building sciences that is about integrating the architect with mechanical engineers and electrical engineers. The energy modelling (or perhaps Energy Engineer) is somewhat responsible right now in doing that. Currently, the architect thinks it’s their job, the mechanical engineer thinks it’s theirs. It needs to be a hybrid between architect and mechanical engineers and energy

modellers. Someone who specialises in understanding those three domains and able to integrate those three together. To have a job description as a whole building design integrator would be phenomenal.

18. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    Most of the output of the optimisations that we have shared with people has not resulted in the "aha" moment. It is more a validation on the designer's intuitions, and expectations. Optimisation did validate our intuition as researches as well.

Developers: Shortcomings

19. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Lack of data. We just do not trust cost data, which is a major problem. Also if we are doing chillers and roof top units we don't have performance data for those. We can only have estimates on how the system can perform.
    - The inability to predict occupants. The building is made for occupants so they operate it to maximize their comfort. So if we want to do integration of optimisations techniques for NZEBs of high performance buildings we have to find a way to model the occupants accurately or stochastically that will help our optimisation. This includes schedules because occupancy drives the Schedules. Computing power. We can use super computers but as I said every building is a prototype. We have to run in the US 75 million commercial buildings and each one is unique. Each one will take 100,000 simulations.

20. **Would you use optimization tools if they were integrated into an energy modelling tool?**

    Yes. The problem is that most optimisation tools are not coupled with building simulation. We treat building simulation as a black box in the optimisation world which black box simulations have been around for a long time. If we want to get better coupling with optimisation and building simulation, then we are going to encounter other issues. Such as run time will increase significantly. Data will get to be more of a problem because now that you are down at a granular level. It will "obscure" the problem for architects and keep the simulation is in an "elite" status. I think it's a good idea to get to this level but we first have to show the benefit optimisation to the design teams..

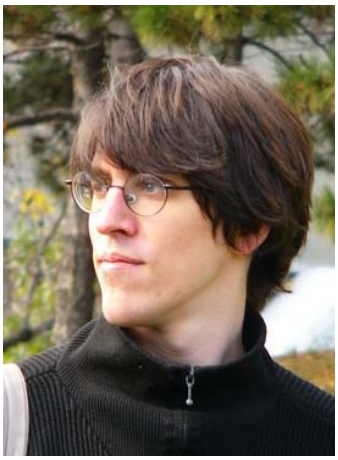
21. **Which tools would you recommend?**

    I have heard a lot of Phoenix Integration I think they are proprietary. Then I would go Matlab after that probably to develop your own stuff. The free tools would be OpenStudio and GenOpt. The problem with GenOpt is that it just manipulates the file by doing string replace. You lose that ability of early phase type of analysis where you are changing major parameters of building like WWR, overhangs, whole HVAC system types

22. **What features would you like to find in future tools?**
    - All data has to be there. Queryable, citable, searchable and accessible. For instance, we should have all the information for light fixtures. I should be able to scan the light fixture with a Smartphone (perhaps RF)and it should be able to give me what type of lamp, voltage, wattage, number of hours running, IES data file, etc

IEA Task 40 Interview with Laurent Magnier, Concordia University, Canada

Interviewed: 09 June 2011 (Lmagnieratgmail.com)



Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building engineering,I am doing a PhD
2. **How do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   For my master thesis I did a multi-objective optimisation for residential buildings. I trained an Artificial Neural Network (ANN) with TRNSYS simulation, and then I used optimization algorithms coupled with the ANN. The idea behind that was to use a neural network to get fast simulations and then have no problem later with genetic algorithms which require a lot of simulation work. [Please find more details in: Magnier, L. and Haghighat, F. (2010), "Multiobjective optimization of building design using TRNSYS simulations, genetic algorithm, and Artificial Neural Network", Building and Environment 45-3, pp 739-746]
3. **How many projects or case studies have you performed?**
   I performed one case study from the beginning to the end by myself and two other case studies using previous work from my colleagues.
4. **Approximately, how long does each project or case study take?**
   As I said my optimisation goes into three steps: first, creating the TRNSYS building simulation file, then run it to build the database to train the artificial neural network; and then running the optimisation with the neural network. So, creating the TRNSYS model took approximately a month in my case. Then the creation of the database for the neural network took around another month in terms of simulation time, but practically it was just matter of pushing one button and waiting for one month for the simulations to run. Finally, the optimisation itself took less than a day using the ANN. Most of the time investment was to create the database to train the artificial network; after that, I could perform the optimisation as I wanted.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   For the ANN, I used the one from Matlab toolbox. For the multi-objective genetic algorithm, I coded it inMatlab. I used multi-objective genetic algorithms so I have to code it myself in Matlab

because it was not implemented yes. I used Genopt only for the parametric runs, coupled with TRNSYS.

6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No, I mostly used existing ones but I had to code the genetic algorithms in Matlab.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   It was residential building in Ottawa, Canada.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   In my case I had seven zones. It was two floors, the second floor was separated between 4 different rooms and there was basement and attic.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   I used five different window areas, thickness of the floor for the thermal mass of the building and then I played with the heating and cooling set points, some delays before stopping and starting the cooling and heating after occupancy. Also some different types of ventilation rates and humidity set points. In fact my work is on passive design and control of HVAC, so envelope and HVAC thermostat parameters.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    It was a evolutionary multi-objective genetic algorithms called NSGA 2. I used genetic algorithms because based on my literature review I found them more applicable to building design.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    I first used neural network to simulate the building and then run the multi-objective optimisation on the neural network because otherwise the simulation will take years.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    No, because the way I did was actual multi-objective optimisation, with Pareto Front, so not just combing all the data in one parameter. So in this way you don't need the sensitivity analysis for the weights. I nonetheless tried to compare the results of my optimisation with some designs I developed myself, just to make sure my optimized solution was good.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    Thermal comfort (PMV) and energy consumption
    b) **What kind of constraints do you set for optimization?**
    I need the rooms to be always comfortable so the PMV had to be in all cases lower than 0.5 in absolute value, and I used bounds for all my variables as well.
    c) **What kind of stopping criteria do you set for optimization?**
    In my case, optimization time was not an issue, so I just let the algorithm run for enough time (10 minutes for instance).
14. **How do you avoid the insolvable solutions space?**
    Evolutionary algorithms explore the whole solution spaces so they cannot get trapped in local minima. In terms of infeasible solutions I had constrains set for all my variables so all my results made sense.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    I didn't have that problem.

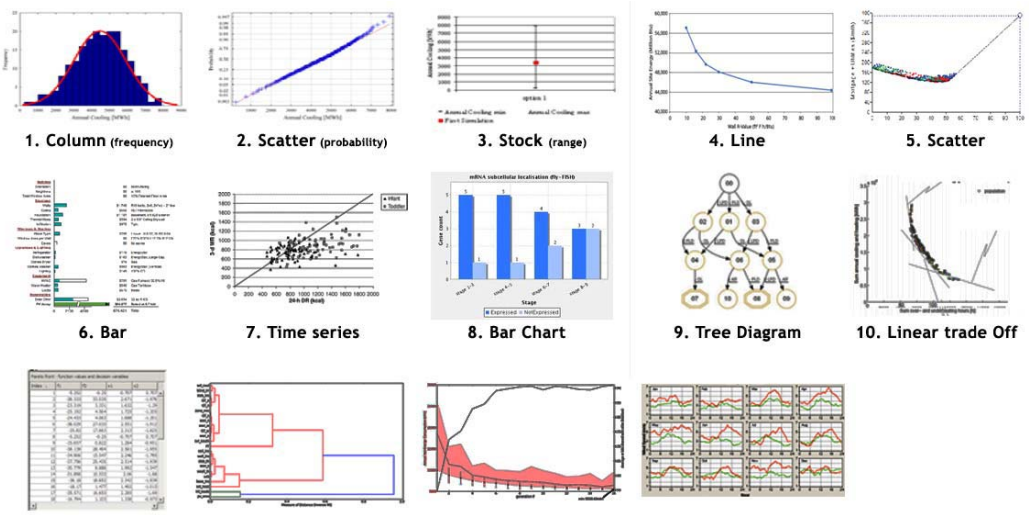
Output

16. **Do you have GUI for your own optimization tool?**

    No.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    I use number 5 the scatter in terms of objective. In terms of variables I just used a table like 11. I once had three objective optimisation and I use a 3D graph in Matlab.



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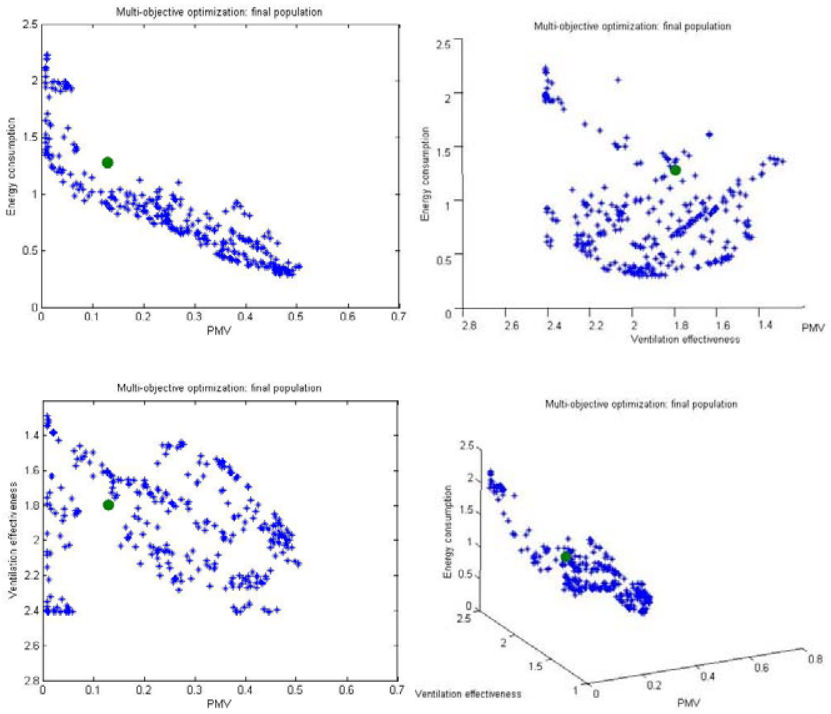
Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (© Elaine Hale), 10 Linear Trade Off (©Christina Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot



From Magnier, Zhou, and Haghighat 2008

Magnier, L. Zhou, L. and Haghighat, F. (2008), 'Multiobjective optimization of building design using genetic algorithm and artificial neural network, Proceedings of eSim conference, Quebec, Canada.

Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    First of all, simulation takes time if you use TRNSYS or EnergyPlus or even CFD. So optimization takes even more time. Also if you do a simulation it will often be used as an estimate for the industry. So if you use only simulation for an estimate you might not want to perform optimisation. And even if you have a very good simulation model it will often be accurate by let's say 10 percent. So you might wonder why you would optimise up to one percent if your simulation tool is only 10% accurate.
    On the other hand, there is a lot of opportunity. If you spend three weeks trying to model a building in EnergyPlus then if you can spend just one week more for optimisation that would be good. It would be a better investment of your time. Still, there is the time constraint and issues with the accuracy of simulation results. On the other hand, if you use software like eQuest or Hot2000 or other fast simulation software then you can do optimisation probably in less than an hour. That would be very useful for early building design.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    In principle, it can fit everywhere. You can use it during early designs for choosing for example window sizes; or use it during later stages to fine tune HVAC settings. You can use it anytime.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    It depends on the software, but I would say only consultants would use it in the first time. However, if it is integrated with different modelling software like eQuest then everyone can push the optimisation button. It depends on how easy it is implemented and integrated in the simulation software you use.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    I think with multi-objective optimisation, where you can show at the same time energy consumption and cost, you can really communicate that Pareto Front to the designers and influence their decision. So I think the multi-objective optimisation can really be used for decision making. However, for single objective optimisation you would need to convince the client that a solution is the best and this is difficult. I think the future will be in multi-objective optimisation.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Computing time
    - Make it clear and easy to use by users on the software side
    - It is only so far for experts because it is not available in main simulation software
    - You need to know what are you doing on the algorithms side
    - You need to convince the industry that it could actually work.
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

Yes

24. **Which tools would you recommend?**

I would definitely go with evolutionary algorithms. For advanced users I will go with multi-objective optimisation because it gives you more information and choice compared to single objective optimisation. I would also recommend Genopt, despite it not having evolutionary algorithms; it is however very easy to use and to integrate with simulations.

25. **What features would you like to find in future tools?**

- Very fast
- Automated so I just put my variables and boundaries and the tool does everything for me.
- I want a descent output
- Default value that makes sense for the algorithms

IEA Task 40 Interview with Peter T. May-Ostendorp, Univ. of Colorado, USA

Interviewed: 11 January 2011 (mayostenatcolorado.edu)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Mechanical Engineer and energy Efficiency Consultant
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Yes, I work on HVAC controls optimisation. My PhD research is about the development of algorithms for mixed-mode buildings. I am not doing optimisation in the design phase but my focus is during the building operation. Mainly, the control side or model predictive control (MPC). The optimal control of mixed mode buildings.
   In our offline MPC studies that we are doing we are trying to derive a new optimal control guideline for a mixed mode building and this could be held to sequentially operated, how to coordinate the operation of the windows and the HVAC system together. One of the large areas of uncertainty in our mixed mode building is the behaviour aspect and human behaviour particularly with the opening of windows. The opening of windows can change the situation and we have to assume a certain mean behaviour in our simulations but that would be different when the building is actually operated. So one of the things we are doing with the results is that once we distil the results down to a real that we can actually implement we then run uncertainty analysis on the user behaviour. So fixing the optimisation strategy and then run a stochastic process around user behaviour to see how this rule hold up against 100 different runs for 100 different user behaviour.
3. **How many projects or case studies have you performed?**
   Difficult to answer but I have been working on a couple of case studies since 2008.
4. **Approximately, how long does each project or case study take?**
   The two case studies were aimed to optimisation of MPC of mixed mode buildings. Off line model predictive control. The idea is to establish
   1- an optimal benchmark
   2- optimal guidelines by developing heuristic control strategies and compare them to the optimal benchmark.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   EnergyPlus and Matlab

6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   No.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Mostly commercial buildings in wide range of climates.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Mainly, multiple zones. Normally ,3 zones per storey and zone multipliers for multiple floor. Also we do core-perimeter zoning incorporating airflow network coupled with the thermal model.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   The focus is model predictive control where we investigate the set point schedules on an hourly basis.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    It is actually particle swarm optimization. It behaves in a similar way to evolutionary algorithms. It's a meta-heuristic non-deterministic. It doesn't care how your model looks like. In fact some of the pattern search algorithms that we have tried take I would say 10 times as long to find solutions that usually are far from the cost of even a heuristic control policy, where is our particle swarm we have been able to cut that time by a factor of 10 and get better answers.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No its most Statistical mode to optimise the model decision...
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    We will be conducting some post-optimization sensitivity analysis to test the robustness of our solutions in the presence of different occupancy patterns, human behaviour, etc.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
       Mainly multi objective criteria mainly: energy, comfort and extreme humidity.
    b) **What kind of constraints do you set for optimization?**
       -Box constraints, i.e. upper and lower limits on decision variables
       -Upper and lower limits
       -penalties (comfort penalties) for allowance
    c) **What kind of stopping criteria do you set for optimization?**
       -Time limit (infinite)
       -Number of iterations (areas of in-sensitivity in the search space)
14. **How do you avoid the insolvable solutions space?**
    We penalize infeasible solutions heavily so that the optimizer gravitates toward the feasible space. With PSO, we are not able to "rigidly" enforce constraints.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    We rigorously test the energy models prior to optimization to avoid simulation failures. A single simulation failure will, at present, crash our entire optimization process.

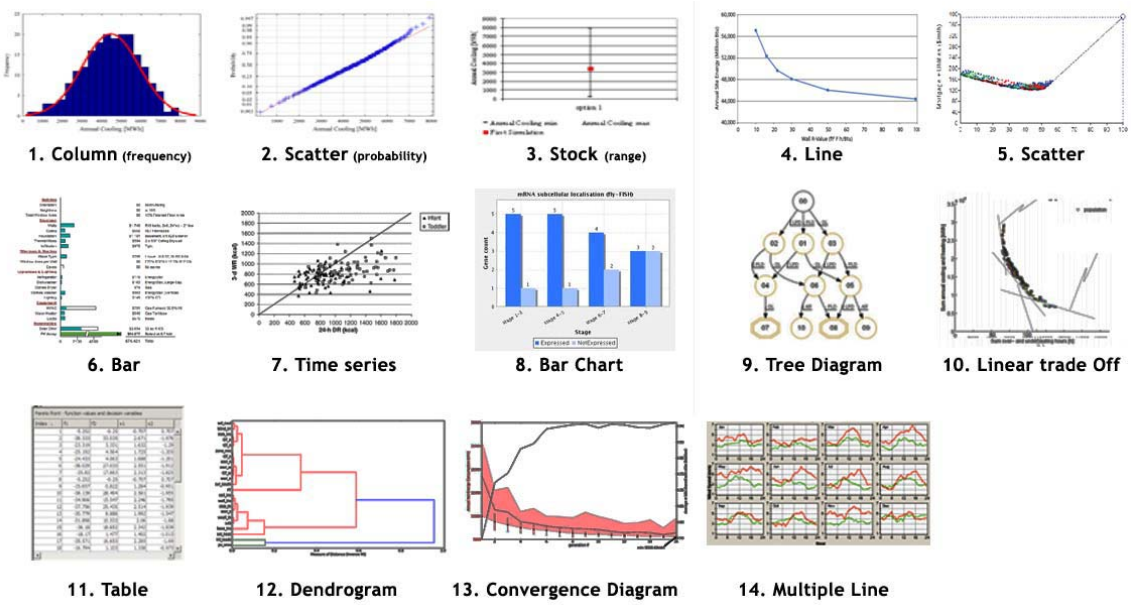
Output

16. **Do you have GUI for your own optimization tool?**

We don't have our own GUI beyond the Matlab interface but we so we do all of our graphs through text command line, but the output we do have a number of scripts that run in Matlab for output processing.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Mainly 7. Line plot time series because we are talking about control. In the case of comfort we will be probably using a scatter plot and we probably use all of the energy saving figures like 8.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    Because this is a very design pointed question I do think that there .. Within the realm of what I do the model predictive control there might be some interest in examining those questions in the design process. The real opportunities lie in tools like BEopt and that sort of thing by examining a wide range of design parameters at one time and findings a sort of cost optimal solution for a given site. I think my work rends itself as well to that.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think for MPC the opportunity comes later in the design phase. In the conceptual phase there more opportunity for the design oriented tools like BEopt. The in the schematic and design development stages MPC has a place to examine if there are better strategies available.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    All designers. BEopt is a great example of that.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

Well I think its most power full on the design side when the tools can be made accessible so an architect or someone with big conceptual theories can use them to guide the decision making. I think that is where it has the most impact.

Developers: Shortcomings

22. What the major practice obstacles of integrating optimization techniques in NZEB design?

- It has no reputation. There is very little information about the benefits of optimisation that will make a head of design team, hire an expert in optimisation. Getting a design team to make an investment in terms of time and having an expertise to guide that process. People are not aware of the benefits.
- The computational capacity that most computers are not enough. Most people are unable to run on a main frame. We are talking about thousands of runs of simulations that can take a day or a week depending on the complexity of the building.
- It is new and people don't trust the results quite yet.
- A lack of professionals in the design world that know how to use those techniques properly. There is a lack of individuals who truly understand what is going on in simulations. Then a smaller pool of individuals that really know how to take those simulations, optimize them and interpret the results and how to understand.

23. Would you use optimization tools if they were integrated unto an energy modelling tool?

- Yes. I think for most software packages today like eQUEST or DesignBuilder or other mainstream products all you have not enough optimisation tools but parametric analysis tools and I think for most users that capability probably suffices. But when you start talking about truly interactive systems that have a larger degree of interaction with the rest of the building. Then I think more comprehensive automated optimisation is really the way to go.

24. Which tools would you recommend?

The first place to look is Genopt, because it is for free and well documented with many existing examples. But there are not many tools so that's it.

25. What features would you like to find in future tools?

- I would like to see better development of simulation tool to streamline or to low run time. So simulation becomes more feasible. As an example, there is certain batch processes that go on at the start of every EnergyPlus simulation. The shadow calculations and the convection transfer functions all that stuff should be done once and that can be left in a file and all future simulations can reference that file.
- Figuring out way to better harness parallel computing capacity. It is difficult if not impossible to paralyze an individual simulation. It is kind of by necessity a sequential task but if you are running a 1000 individual simulations in OptiPlus or whatever it's called. That should be parallelisable. So figuring out ways for people to easily do these things in cloud computing or clusters and that sort of things are valuable.

IEA Task 40 Interview with Monjur Mourshed, Loughborough University, UK

Interviewed: 11 January 2011 (m.m.mourshedatlborodotacdotuk)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Graduated with a professional degree in architecture and received my PhD in civil engineering.
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   My interests in optimization are from an academic point of view. I have conducted optimization tasks in part to lower energy consumption and carbon emissions but the real focus was on the integration of multiple domains in the optimization process. For example, my PhD was on optimization for architectural decision making at early stages, in which the problems are ill-defined and requires inputs from several disciplines.
3. **How many projects or case studies have you performed?**
   Difficult to put a number to. Every year I have one or two postgraduate student working on various aspects of optimization: from the formulation of the problem to decision making. At present, I am working on lighting design optimization and space layout optimization.
4. **Approximately, how long does each project or case study take?**
   Usually in the order of months, rather than weeks – mainly because we use dynamic building simulation for performance assessment, which is rather time consuming. For the first couple of initial runs, the most of the time is spent on tuning/tweaking/correcting the connections between the algorithm and simulation programs.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   Mostly employ my own algorithm (coded in Java and/or C++). Previously I have used MATLAB's Global Optimization Toolbox and U of Illinois' implementation of Deb's NSGA.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, in Java and C++.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Commercial buildings in moderate and cold climate.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   One to several zones.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, Comfort, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Mostly geometry and building envelope. Shape or form of building, envelope properties, etc. Recently we have developed an optimization framework to determine optimal positions of luminaires in a room.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Mostly Evolutionary algorithms. I have used gradient-based algorithms in the past, which have a tendency of getting trapped in local minima. Evolutionary algorithms are probably better suited to building optimization problems mainly because most solution landscapes in building design problems are discontinuous (depending on underlying performance evaluation).

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No, not neural networks. Used interpolation to some extent.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    I would do some research before formulating an optimization problem; to understand the solution landscape. I investigate objectives and design boundaries either by using a 2D graph or a 3D surface plot; in a sense you can call it sensitivity analysis, albeit visual.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

       Depends on the problem being studied. For example, for an interior lighting design problem, the initial objective was to achieve a uniformity of horizontal illuminance. But the brute force simulations suggested that the vertical illuminance was varying a lot with instances of bright patches, with impacts on visual performance of the occupants (over the age of 60 in this case). Therefore, the problem was reformulated as a multi-objective one involving the investigation of two objectives: horizontal and vertical illuminance.

    b) **What kind of constraints do you set for optimization?**

       Varies. For example, in the lighting design problem, maximum and minimum illuminances were set as constraints. Most of the times, the limiting values come from design and industry guidelines and building regulations.

    c) **What kind of stopping criteria do you set for optimization?**

       Depending on the problem it could be maximum number of generations or a particular value of the objective.

14. **How do you avoid the insolvable solutions space?**

    Depends how you define the insolvable solution space. If it is an inherent problem in the problem formulation, we try and redefine the problem. In any case, we try to reduce the size of the solution space either by using knowledge (from previous runs) or by using guidelines.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    It happens more often than not. The solution usually involves looking at the model and conducting a few parametric runs. To tackle the interruption issue, we have used memory in the past; i.e. you keep a track of the progress of optimization and if it breaks, start again from the where it got broken.

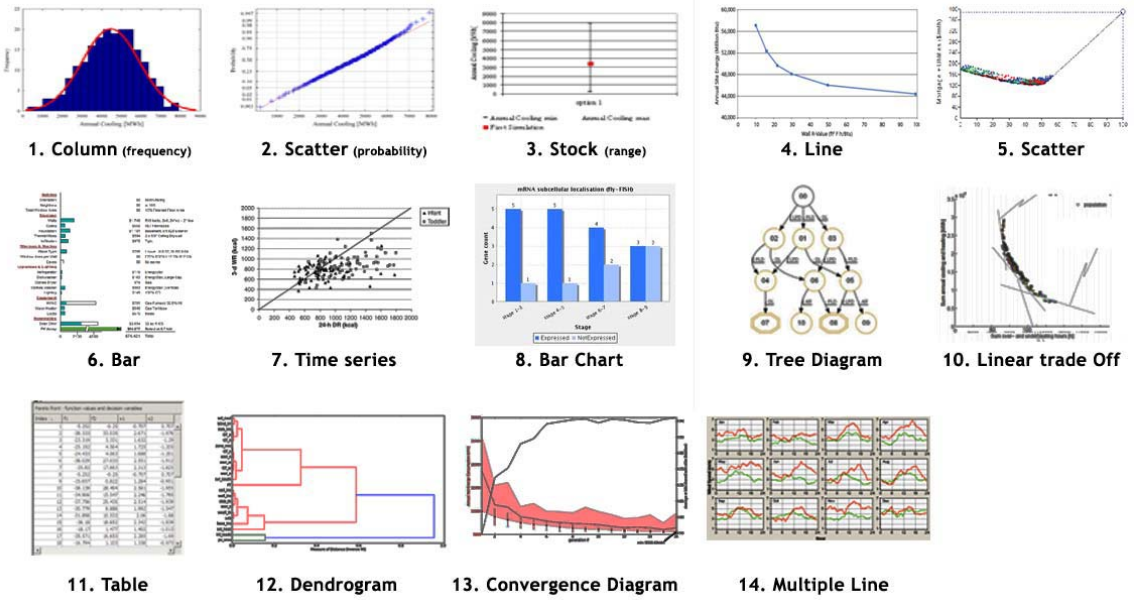
Output

16. **Do you have GUI for your own optimization tool?**

    I have a tiny GUI that kind of shows the progress of optimization with plots of best individual in a generation or the population with best fitness and sometimes constraint violation.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Figure 4 and 5.



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Integration with Design Process

18. **What opportunities you see in integrating optimization techniques in NZEB design process?**

I am tempted to say that there are endless opportunities for integrating optimization in the design process. Traditionally, buildings are designed based on heuristics or past experiences, at least during the early stages of design. By employing optimization techniques designers/team can choose the best direction (of the design) and have a better understanding of the solution landscape.

19. **How does it fit into the design process? At which stage of the building design process should optimization techniques be used?**

It should ideally start with early design stages but detailed design stages are most feasible for adoption partly because that the problems can be better defined. In fact, there is no theoretical barrier as to the suitability of using optimization at different design stages. What may limit its use in early stages is the lack of interoperability between software and disciplines involved and the apparent fuzziness in the definition of the problem.

20. **Who will be the user group? Should optimization techniques used by mechanical, simulation consultant, engineers or architects tool?**

It could be and should be used by everybody who has an interest in design decision-making.

21. **How can it be integrated into the decision making? How should optimization become more practically applied in early design phases?**

There exists a number of tool but at the end of the day it is not always about the tool or what it can do. It is more about the organisational culture in the construction industry and that we are reluctant to change.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Interoperability between software programs (CAD, Simulation, etc.) and disciplines
    - Problem definition
    - Suitability and effectiveness of algorithms
    - Visualisation and decision making
    - Lack of simulation software that has integrated optimization features
    - Construction industry is slow to change
    - Lack of knowledge of the usefulness of optimization in design process by the industry.
23. **Would you use optimization tools if they were integrated unto an energy modelling tool?**
    Yes. Personally I would.
24. **Which tools would you recommend?**
    Best to develop own optimization algorithm in a programming language the developer is comfortable. As for the simulation program, I would use EnergyPlus for energy related simulations and Radiance for daylighting/lighting.
25. **What features would you like to find in future tools?**
    - My top priority for a desired feature would be interoperability; i.e. the ability to call a program as and when needed without the need for translation and error checking.
    - The second most important feature for me would be an effective visualization system that enables an effective exploration of the solution landscape as well as the process of optimization.

IEA Task 40 Interview with Tatsuo Nagai, Tokyo University, Japan

Interviewed: 16 November 2011 (nagaiatrs.kagu.tus.ac.jp)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Engineering (in Japan there is no separation between architecture and engineering)
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   We have one research that is about set room temperatures trajectory (daily or longer terms) by using building thermal storage to minimize integral electricity consumption during daytime, for minimizing peak electricity demand. The optimal results is to cool under the limit of set point during the night time and before occupied tours starts then the temperature rises back to lower limit of the room temperatures. That is the kind of results we seek using optimisation. Other research is about HVAC optimisation. We use HVAC and envelope to reduce energy consumption.
3. **How many projects or case studies have you performed?**
   Mainly two projects.
4. **Approximately, how long does each case study take?**
   For the first project it took five years and the second it took two years.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   For the former one we did not use specific tool we developed our own way using dynamic programming. For the second one we use Simulink and Matlab with the linear optimisation toolbox in Matlab.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, for computational efficiency we are using dynamic programming and we model each components of HVAC in Matlab. We have not modified the optimisation algorithms or model.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Non residential buildings, mainly office in Japan, but the methodology can be applied to any weather condition
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   For the former project it was only a single zone and for the second project multizone. We wanted to consider multizone even for the first project but the methodology is only mainly applicable to single zones.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   HVAC and controls

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Deterministic algorithm for both cases, I haven't tried evolutionary algorithms but I suppose it is not efficient by the evolutionary calculation and I won't calculate or trust evolutionary algorithms. I think it is robust but it is based on trial and error method. I don't know which result is the right one or is it really optimal or not, but actually the non linear programming is also not optimal because it may suggest local minimal which is limiting.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    No

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    Energy consumption, integral energy consumption, peaking demand, integral energy cost.

    b) **What kind of constraints do you set for optimization?**

    Comfort, mainly admissible room temperature during daytime if for example the admissible room temperature is 23 ^{o}C or max temperature is 26 ^{o}C for comfort. For the second project many constraints were used to minimize flow rate passing in heat pump and other practice recommendations.

    c) **What kind of stopping criteria do you set for optimization?**

    No stopping criteria because it is not evolutionary or iterative procedure. The convergence is determined by the difference of control variable between the two iterations or the difference of objective function between iterations.

14. **How do you avoid the insolvable solutions space?**

    We don't set only one initial point but we set several initial points to avoid being trapped in local minima.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    We just use Matlab package and so we check the error message and revise the input.

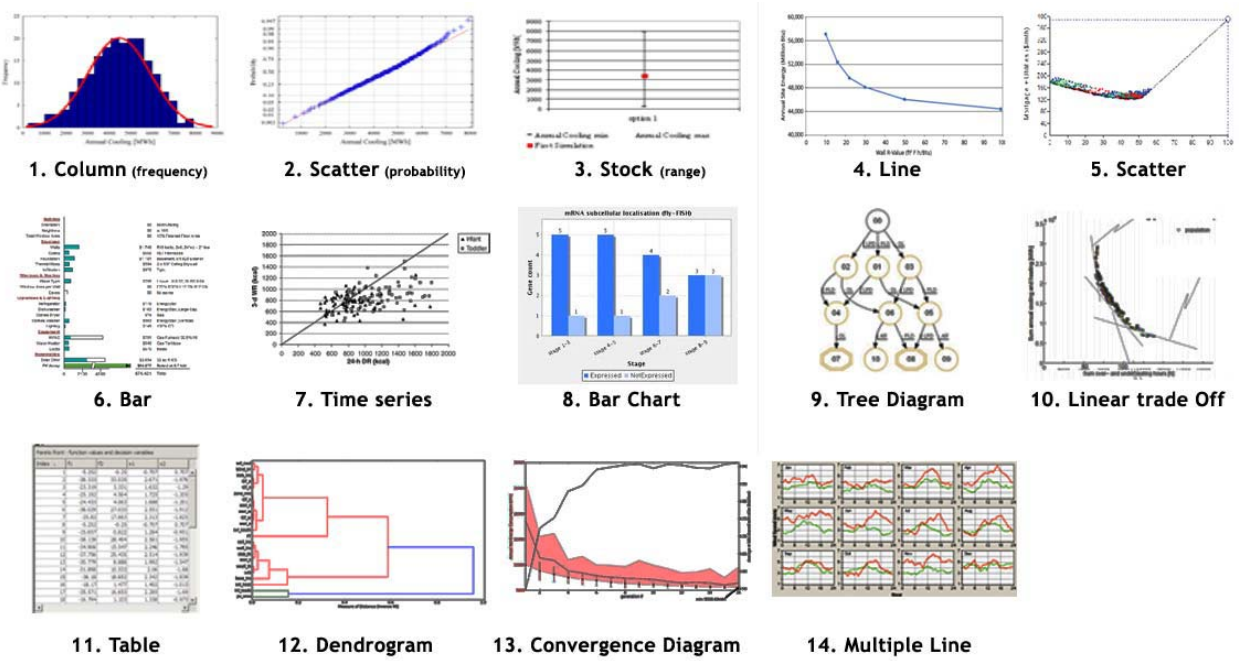
Output

16. **Do you have GUI for your own optimization tool?**

    No, we use excel or Matlab or other graphical software

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Mainly Pareto, time series and scatter like 5 and 10.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Yes, I think reducing energy consumption and initial construction cost.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Mainly early in the design process of building.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    It should be done by architecture designer, for HVAC it should be used of course by mechanical engineers. But it is difficult because the GUI is not friendly.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    You should present some options of design A, B and C. In that process the engineer should present the most suitable systems to the client. Because many criteria exist when choosing the system not only energy or cost but also the building space, so the engineer should prepare options.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Control protocol and communication between appliance and central control unit. It is not universal and depends on specific manufacturer. So there is no uniform protocol related to communication.
    - Also the reliability of optimisation calculation. There is a very high risk to apply optimisation techniques directly to control systems. If the solution is not derived from the optimisation, the appliances will stop. So I think there is a need to another option when optimisation fails, or set near optimal solutions.

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

Yes, hopefully a universal methodology exists. For example, when using Matlab toolbox where simulation and optimisation is divided, but in that case the calculations are not efficient. So it is better to combine simulation and optimisation to avoid contradiction.

24. **Which tools would you recommend?**

I recommend Matlab toolbox because it is easy linked with Simulink for analysis.

25. **What features would you like to find in future tools?**

The optimisation should present options that are quite different from each other and that can't be imagined by designers. Maybe, the rough decision should be made by designer so optimisation should give solutions for the design process. In the future and in the control case the optimisation can be directly applied to the control systems automatically. Optimisation should provide also during the design process different solutions.

We should be careful about understanding the results and the solution interpretation from other solution were derived because if we can interpret the results given by the optimisation. We can construct near optimal strategy for design and control.

IEA Task 40 Interview with Matti Palonen, Helsinki University of Technology, Finland

Interviewed: 30 August 2001 (matti.palonenataalto.fi)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Computer science
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   It started six years ago when Dr. Alaa Hassan had some optimisation cases using Genopt. We started to develop the genetic algorithms at the same time and we used that case that Ala Hassan had optimized to test the GA. That how it started actually, so I was asked to develop a genetic algorithm. I am not actually designer but what I do with simulation tools I use math-functional optimisation.
3. **How many projects or case studies have you performed?**
   Depends on how you define case study. We did not do case studies for a particular building to optimise it. I do not think that people do automated optimisation in practice or real case studies.
4. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   I used population based methods, line search and random search in GenOpt and linked it to IDA. So I developed the interface between the genetic algorithm and IDA and then we used that to develop a proof for search too. At that point we started to imbed it in the GenOpt framework. At this moment, we are starting to release three different genetic algorithms, hopefully at the end of this year. You can go to the Genopt website and you will find our previous work documented there. There is a list in the GenOpt webpage with the GenOpt related publications.
5. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes I developed a genetic algorithm and its proof search in Java.

Methodology

6. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   We have been working with a single house cases and an office house case, mainly with the climate data for Finland climate.
7. **How many zones do you address when running optimizations? (Single zones – Multizones)**

Single and multi-zones.

8. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Mainly envelope and systems depending on the case study.

9. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

   Both or hybrids. In one of our published works we used a genetic algorithm to generate the initial points for deterministic algorithms and deterministic algorithms convert to the true Pareto Front. We wanted to see which algorithms generate a better initial point for Hook Jeeves algorithm. Previously Dr. Ala Hassan has used the particle swarm optimisation to generate the initial points. SO we used genetic algorithms with the same number of functions simulations and compared which algorithm generated better initial points for deterministic algorithms with the same number of simulations. The conclusion was that the genetic algorithm generated better initial points for deterministic algorithms compared to particles swarm optimisation, but we cannot generalise this because this was only one problem for both algorithms.

10. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No. I am going to this year.

11. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Yes, empirical.

12. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    Cost, energy, cooling beam size.

    b) **What kind of constraints do you set for optimization?**

    Comfort.

    c) **What kind of stopping criteria do you set for optimization?**

    Maximum number of simulations

13. **How do you avoid the insolvable solutions space?**

    Nothings, with simulation model the functions are like black boxes so there is nothing I can do but from my experience we have some models that can be quickly calculated so we can have a picture or idea of the search space. Also I think that genetic algorithms can explore the whole space.

14. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    Record all points

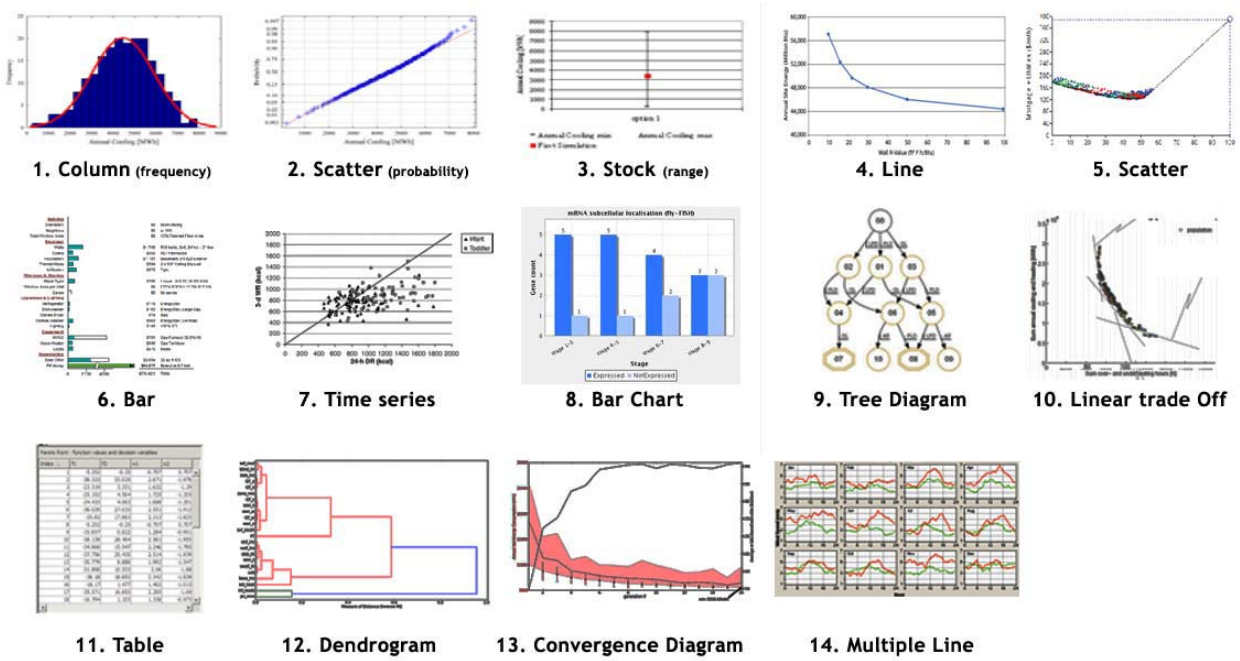
Output

15. **Do you have GUI for your own optimization tool?**

    No, but I use Gnuplot

16. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Mainly scatter 2 and 5. I prefer two dimensional graphs because they are clearer.



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Integration with Design Process

17. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think that right now the largest Finnish building companies are not interested in such sort of approach. I think that it is not profitable at this point maybe later in the future. I got this feeling and there was a sort of task to check how the companies would use the information provided by optimisation techniques.

18. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think during the whole design process but you need to define well the variables you will change. So you will change a set of variables depending on the stage you are. Also you should be aware that you might optimise something but you get another not wanted side effect. So I think that when you optimise something you get something else bad maybe you won't see that side effect. That is because you have to choose certain variables and objectives and leave other variables. So for an optimal solution it will be dependent on the objective set of variables.

19. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    Hopefully in the near future a normal designer might use optimisation techniques, but we have to provide first some tools to make decisions fast.

20. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    First of all the user interfaces for optimisation programs are not good enough. If you used before MathCAD you will find it having a beautiful interface for inputting equations but it has fairly limited optimisation tools. So it has one good side (equations) but the optimisation side is not so good. Another example can be GenOpt which has a particle swarm directory. It is a good approach but the interface of GenOpt is hard to use for beginners. So there is a lot of available

software but none has comprehensive features. Every software has good side and bad sides and we need one software that entails the qualities of all software's in one package.

Developers: Shortcomings

21. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    I would say the biggest obstacle is the interfaces frameworks. The other big problem is how to define easily from a model a text file including the decision parameters. I mean that is hard. It seems like a simple task that you have that model as a text file and then you need to tell the optimisation program where to find the variable range of value and where to change them in the text file. I found this a real problem with many people and there is no a standard solution to do which make it hard for designers. Also there is bad documentation (in some cases does not exist) of the simulations programs.
22. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes.
23. **Which tools would you recommend?**
    None I have seen.
24. **What features would you like to find in future tools?**
    It has to be interactive and you can speak to it. It might be like a visual friend or visual advisor to help you. You could ask him a question and he answers you. The kernel could be some optimisation technique. It is actually happening now with road-maps. There are applications that help you to find roads using approximation algorithms that solve these problems. For example there are applications on internet where you can ask how to go by bus from Helsinki to Turku and it finds you a road and itinerary. So future tool might include such oracle or wizard friend.

IEA Task 40 Interview with Christian Struck, University of Applied Sciences Lucerne, Switzerland

Interviewed: 06 June 2011 (christian.struckathslu.ch)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building services engineering and integrated building design.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem (Sensitivity analysis, Uncertainty analysis, Optimization, others)**
   Yes, we work on a project which investigates: "How to convert the existing residential building stock in Switzerland to buildings with positive energy balance on a yearly balance basis". We started the research project by establishing typical user/occupant profiles of the existing building stock. The initial aim is to minimize the impact of the building fabric in the buildings current status. Further we target the optimization of different technologies to generate and distribute heat and electricity. The key parameters for reducing the heating demand of domestic buildings are well known. Sensitivity analysis for plant component parameter was not yet necessary as the number of parameters was limited. Optimization has proven a valuable tool to identify the building specific key values for e.g., orientation and inclination of PV-panels.
3. **How many projects or case studies have you performed?**
   The simulation studies are based on one typical residential building layout. The minimum necessary building standard with and without ventilation is considered. Four different technology scenarios are simulated.
4. **Approximately, how long does each case study take?**
   The project runs over a year and the initial case study conducted took approximately a week to set up model and analyse. We had problems to conduct more extensive case studies why the initial focus was on the building fabric. Actually we just finished a paper that we submitted to the Swiss IBPSA conference. Detailed modelling of plants (Heat pump, storage, DHW etc.) requires additional time. I estimate one week extra for a good running building and system model. The process requires understanding the component models, coupling the component models and controlling the system behaviour to represent a realistic performance.
5. **What kind of tools do you use for optimization (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**

We had an IBPSA workshop here in Switzerland during CISBAT 2011 conference. We wrote a paper comparing the three different tools (BeOpt, GenOpt, Topgui). We decided to go for GenOpt. We couple GenOpt with IDA ICE. We also considered BeOpt and TopGui.

6. **Have you developed your own optimization algorithm? (if yes, which programming language)**
   We limit ourselves to the algorithms embedded or provided by state of the art tools.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   The current focus is on the existing residential building stock in Switzerland, as they represent the biggest saving potential. We also look at commercial office building but not in the frame of the current research project mentioned earlier. Switzerland is very diverse in climate due to extreme altitude differences. This is considered by investigating three different locations.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   It largely depends on the question we are trying to answer. The base case model uses one thermal zone for each room. From the base case load profiles were derived. When optimizing the plant response, we only use the load profiles at first. Later, we will go back to the multiple zones models to test the settings. What we normally do is to differentiate between heated and non-heated zones. We also differentiate between frequently and less frequently used spaces of the building.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, Daylighting, PV, Renewable systems etc.)**
   At first our focus is on HVAC system parameters in combination with solar systems (PV and solar collectors). Secondly, we consider the building fabric to identify the standard of the building fabric required to achieve a net zero or positive energy balance.
10. **What kind of optimisation algorithm do you use? (Deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    GenOpt stands for genetic optimisation and within GenOpt you can choose from a variety of algorithms so you can go for GA's but you can also use deterministic algorithms. It really depends on the optimisation problem. We started with Hook Jeeves, but this algorithm doesn't ensure finding the global optimum. So now we are testing particle swarm algorithms to see if we can get better results.
    Alternatively one can use multi-objective optimisation algorithms (MOOA). MOOA's provide a number of equally good solutions from which the user needs to filter the most suitable.
    In building design we try to identify the parameters which provide the best performance across multiple performance indicators. So we try to get the best results under the given constrain.
    So we need algorithms, which search the entire solution space and then provide one best single solution for the considered parameters.
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    We apply sensitivity analysis first on the integrated building design aiming to identify those parameters that are worth tweaking to improve the building performance. From there we come to the discipline specifics. My current view is to work the process iteratively: sensitivity and uncertainty

analysis first, interdisciplinary – optimisation, individually which is followed by a second round of sensitivity analysis and optimisation.

13. **Under which setting you run your optimization? What is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    Energy consumption is the main objective from which we can derive carbon dioxide and primary energy savings.

    b) **What kind of constraints do you set for optimization?**

    We usually set the comfort as a constraint. We define it with specific set points for heating and cooling and then from there we look at the demand. Be aware of the fact that the demand profiles provide constraints to the heat exchange and plant model parameter such as heating supply and return temps, and heating threshold temperature.

    c) **What kind of stopping criteria do you set for optimization?**

    We stop the simulation in case the residuals diverge. The number of simulation runs are at first limited to a fixed number, say 100. The results are then analysed and if necessary the number of simulations adjusted.

14. **How do you avoid the insolvable solutions space?**

    The quality of results from optimisation depends on the optimisation problem and choice of algorithm. Experience shows that one need to properly define the problem first (cost function) and avoid algorithms which run the risk to get trapped at local optima such as gradient based algorithms.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    We have not noticed failed simulation yet. The coupling between Genopt and IDA-ICE work without problems.

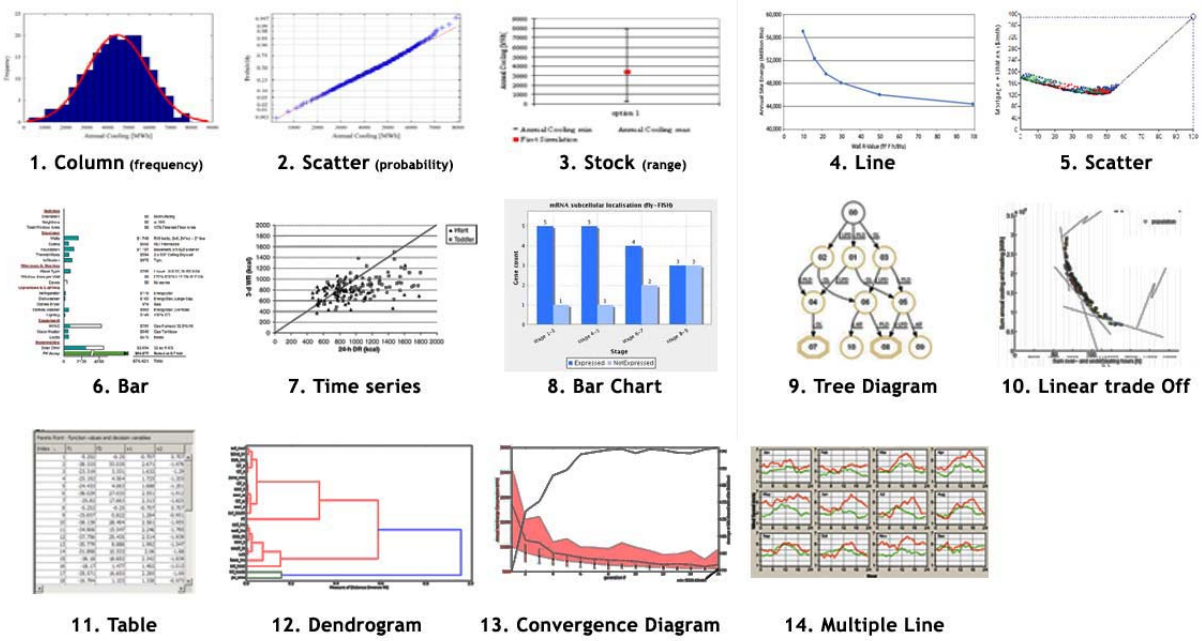
Output

16. **Do you have GUI for your own optimization tool?**

    No. But we are working on a project that aims to develop alternative approaches for communicating performance data. See the work of Marc Steimer at http://www.rgbsammelstelle.ch/info-screen11/marcsteimer/main/index.html.

17. **Which kind of output analysis visualisation did you use with optimisation tools? (1-14)**

    The most common are 11(tables). We also use 4 (line graphs) and 8 (bar charts).



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques into the NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    In terms of energy savings the opportunities are enormous. The target market should be the existing building stock as we speak about annual local renewal rates of 1-2%. The greater diversity of supply systems in NZEB design requires better and coordinated systems controls. With respect to decentralised and smart grid optimisation is an important tool to fit demand to supply profiles.

    We published a study last year where we identified the energy savings that could be achieved in buildings by commissioning and building energy management. We concluded that it is not unrealistic to save up to 20 % of the final electrical energy use of Switzerland (2007).

    To my understanding optimisation has its place in the design and operation stage of buildings.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    I think it is a huge challenge to get optimisation integrated into the design process but I am confident that the development of tools as BEopt (NREL) targeting home owners to identify the cost and the potential of integrating renewable systems are advantageous.

    Optimisation should not be limited to one design stage. It should happen continuously during design and operation. I anticipate that advances with the Building Information Models (BIM) also facilitate the use of advanced analysis such as building performance optimisation.

    However, the problem with BEopt is that it is targeting the North American and has a limited GUI. Despite the wide output variety the measures you can tale are limited. For example if you want to look at CHP systems you soon reach the boundary of the tool.

20. **Who will be the use group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

Currently it is the building performance simulation expert or simulation consultant. In the medium term with the advances in BIM I expect new professions such as “model manager”, “master modeller” and ”performance manager” to emerge coordinating the work on and with the model. By that time I anticipate the individual discipline specific engineers to optimise their contribution to the design on the BIM directly.

21. **How can it be integrated into decision making? How should optimisation become more practically applied in early design phases?**

If you want optimisation to get better integrated and convinces clients to use it you should first raise awareness to the difficulties we are facing with it: choice of algorithm, definition of cost function, maintenance of net-zero or positive energy balance over the buildings lifecycle.

Better integration can only be achieved by realistic expectations and tools which have the capability for parameter optimisations. Those tools need to be adaptable to specific stakeholders needs e.g., architects and services engineers.

Be aware that the demands on NZE buildings are not fix but will increase. The energie-cluster.ch defines three types of buildings with positive energy balance.

Type1: The current target is to achieve a positive energy balance considering electricity, heating and DHW demand. Type 2 integrates the grey or embedded energy. Type 3 also considers the demand for mobility.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

- Selection of the optimisation algorithms. So the optimisation algorithm needs to suite the cost function you want to optimize and it also needs to fit the character of the parameters (discrete, continuous etc.).
- Coupling the building system model to the optimisation algorithms. Standardised coupling procedures will be useful.
- Multi-objective optimisation: Concurrent consideration of multiple performance indicators.
- Robustness assessment: of optimised building systems. How you will the optimise building systems perform under a changing climate and different use pattern. During design you either strive towards a flexible or efficient design. There is limited knowledge available on how to assess and benchmark a design’s robustness.
- Detailed Tools with optimisation capability: better tools which allow easy handling of the performance data and communicating the saving potential (see http://www.evalo.ch/).

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

Yes. I think Energy 10 included both features.

24. **Which tools would you recommend?**

I suggest coupling detailed simulation tools e.g. TRNSYS, IDA-ICE, esp-r with external optimisation engines such GenOpt.

25. **What features would you like to find in future tools?**

I think we will need more decision support for selecting parameter sets from optimisation tools. We need stakeholder-centric communication of building performance data. One important aspect is standardised coupling-procedures for tools. Michael Wetter developed the building control virtual test bed (bcvtb) which proposed one route. Another route could be following the BIM standards.

IEA Task 40 Interview with Mika Vuolle, Equa Simulation Finland

Interviewed: 16 May 2011 (mika.vuolleatequa.fi)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   HVAC Engineering (consultant and researcher)
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
3. **How many projects or case studies have you performed?**
   The first one was residential buildings. Then we have used in office building because we optimised closed wet cooling tower system in the cooling system and it was office building and the rest is 4 or 5 cases that are also office buildings as well.
4. **Approximately, how long does each project or case study take?**
   From one single zone to 15-20 zones. In single family house I add into the Genopt the LCC function. In that function we fed the first cost, initial cost and annual energy cost. Then we calculate the LCC of that and our approach was that we use our basic case which has a LCC of zero and then we compared it to the additional investment you needed for every different parameter in the building.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We have used one of the algorithms developed by Michael Wetter (GPS Heeg and Hook Jeeves). Lately we have used Genetic algorithm written by Matti Palonen.
   I couple it to IDA ICE.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   In Genopt I wrote a tiny piece of Java code that is the LCC change calculation. So we didn't need any post processing.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Residential and office in Finland.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Single and multizone ranging from one single zone to 15-20 zones.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

Also we calculated the energy consumption to see the difference of annual consumption compared to basic line. In the single family house we had different kinds of heat recover efficiencies, supply air set point, envelope wall U-Values, roof U-value, Floor U-value. Thos U-values where continuous parameters so we actually consider the thickness of insulation layer. In the same study we had 4 or 5 different types of windows as discrete variables. One type has U-value, G-value, solar value properties of the window glazing in addition to shading devices.
In the cooling tower situation we studied the set points and controls, operation control strategy when it should be turned on and off, outdoor temperature set points and how to run the cooling tower in optimal way to achieve maximum COP of the cooling tower. Then in this underfloor cooling combined to chilled beams we tried to optimize the might time cooling in the building (we had also insulation thickness and window types in the offices too).

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    Evolutionary algorithms. I select them based on their performance. I used the first because it will generate a population. So I do it in parallel and even it won't find the optimal solution but it's optimal for me due to that. Because I can run 8 cases in parallel and will make the case really fast.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    No.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    LCC and comfort. Comfort was done using the PPD and PMV values, using Fanger equations.

    b) **What kind of constraints do you set for optimization?**

    Comfort, any case not fulfilling to the comfort constraints was neglected.

    c) **What kind of stopping criteria do you set for optimization?**

    Number of simulations 300 maximum. So it was the default criteria from Genopt. We didn't deal with that. We didn't consider that interesting because in any case we run the simulations over the weekend.

14. **How do you avoid the insolvable and infeasible solutions space?**

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    We had some situations that were mainly due to modelling problems for fresh components and not for optimisation.
    In the case of single family house we didn't have any problem but in the case of the cooling tower model I wrote many scripts that were not tested and very widely used once before. So some insolvable solution spaces appeared.

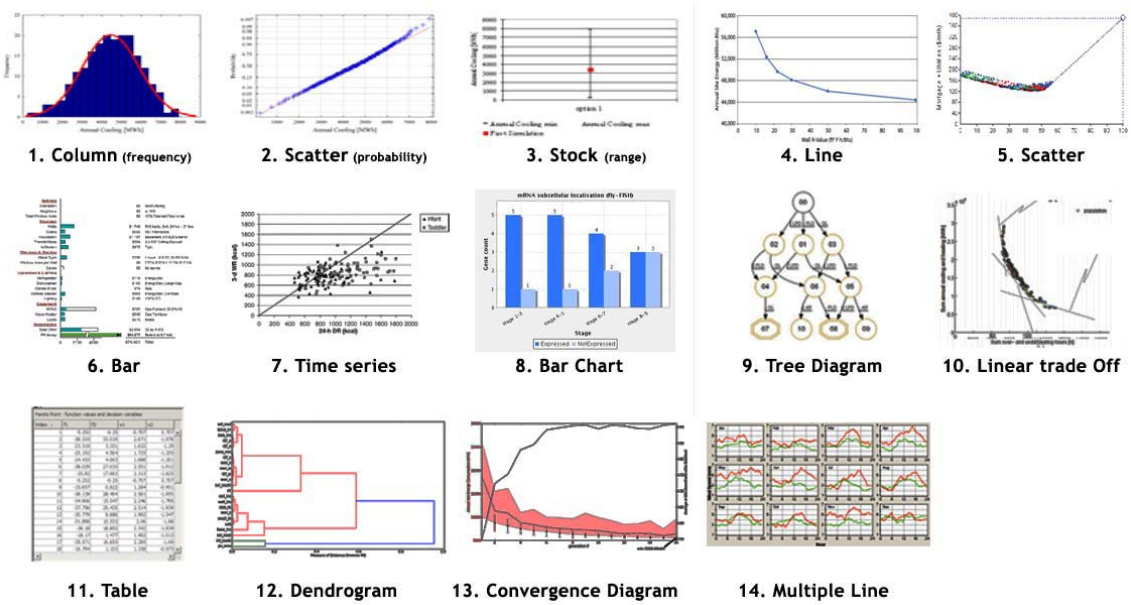
Output

16. **Do you have GUI for your own optimization tool?**

    No. In Genopt we would use post processing to visualise how the genetic algorithm found the optimal solution. SO we make a Pareto Curve. In this cooling tower case we plot out cooling tower COP. In single family house we actually visualise the LCC change and the other access of other parameter (U-Value). In both cases it was pretty much visualisation of the results and the procedure and how it gets optimised.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Scatter chart (5) and line (4) we sort out when we have initial cost and energy.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    The use of optimisation in NZEB design is very interesting because we are not only addressing the demand side but we want to optimise the production side (including PV solar panels, wind mills, heat pump etc.). So finding the optimal design by hand using lots of man power is very hard in this context. Automatic optimisation is even more valuable when we try to achieve NZEBs. The other point is that we have to be really careful once we do these studies became the average in time period (e.g. monthly study) you will discover that you consume more that you produce but if you have a little bit shorter time resolution you will notice that you can't use the electricity that you will produce to cover your needs. So matching the loads has to be taken into account. It means that you have to use more detailed simulation and with detailed simulation you will need more time to reach the optimal solution, which makes it not doable in practice. So for NZEBs we will need more detailed models and to find optimal results we need to use optimisation. We will need automated optimisation.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    It depends on the case, but it should be used in every case and it's true that the biggest decisions are made in early phase but then we will play with geometry and the building layout. Those things are not easy to optimize but window area is easy to optimise and overhangs and other shading objects. Once you have an idea on the shape of the building you can optimize the systems and control strategies. So I see the use everywhere between those stages. The limitation is how you describe your optimisation problem in a way that makes it run automatically. That is the challenge.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

I think that it should be the team. There should be a simulation expert who can do or merge the optimisation and give the results. Then there should be architects who should throw out the ideas and be in the loop as well. I think it can't be a single person it should be a team that all works together on a common goal and target. It can't be done by a designer who will manage whole process it should be a team.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    The decision making is a hard topic because if we optimise the window area for example it will be only one parameters or elements that you have to be aware when you change the window area. But there are other topics as well. For instance how the building looks like, how stable it will be so in this decision making the optimisation is one egg in the basket and there are 11 other in the basket. Even if optimisation will give some results and we decide to neglect it then we take the decisions consciously for other reasons and it will be good to know what the other reasons are. It is valuable information as well but there are other topics that have a bigger weighting factor. As I said this is only one egg in the basket. Buildings are not built for the reason to be energy efficient they should look nice and have the right materials and colours and suitable for tenants. There are other issues as well.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Defining the problem for sure.
    - The good news that the Euro is a good consultant. Money is the key issue. We have to have first cost, initial cost and energy cost in Euros. But how can we find the cost information. We need the value information. In some cases they are really hard to describe. There are discontinuous ones and so on. This is a hard issue not in terms of optimisation but in the information on cost
    - Optimisation is so far away from daily practice and work. For example and HVAC designer if you ask him what your constraints they will know what are you talking about. They don't understand what it means and what it can bring.
    - Also there is a lack of knowledge and experience and interest because in real projects they have really lack of time and man hours that they can use
    - How to use the tool in daily practice
    - Long running time
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**

    Yes, there should be complete packages for end users and researcher
24. **Which tools would you recommend?**

    It depends. If you have Matlab on your computer use Matlab with IDA or EnergyPlus. The main issue here to use any tool is to find any kind of support when starting using the tool.
25. **What features would you like to find in future tools?**
    - I want to have add-on features for simulation tools. So on top of simulation user can buy or use an optimisation tool box that is fully coupled with simulation tool
    - Easily describe the problem with some fixed cases where you have some basic parameters for simple interfaces to do for example optimisation of night ventilation. Because otherwise it will be very complex to explore the whole solution range, too complex to run and too complex to understand.

IEA Task 40 Interview with Weimin Wang, PNNL, USA

Interviewed: 06 January 2011 (WeimindotWangatpnldotgov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building Engineering
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Yes. We did consider the use of optimisation in several projects for energy efficiency in new building design and existing building retrofit but we had limited success. We usually do sensitivity but not uncertainty analysis to support/verify optimization results .
3. **How many projects or case studies have you performed?**
   I used two hypothetical case studies in my Ph.D. work. My Ph.D. topic is Simulation-Based Optimization for Green Building Design. We have a couple of ongoing projects to pursue optimization for two real buildings.
4. **Approximately, how long does each project or case study take?**
   Ranging from one to several months per case.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   I ever used Matlab to verifiy the optimization results from my own tool. We tried using NREL's OptEPlus for commercial buildings.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes. I programmed with C++.

Methodology

7. **Which building typologies have you used optimization for and in which climate? (Residential, Offices, Retail, Institutional)**
   Commercial buildings (office buildings) in hot humid climate.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Both single zone and multiple zone models. For real buildings we do full building representations.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, Comfort, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, others)**
   For my PhD work, I considered mostly about building envelope related design parameters which are major considerations at the early design stage. In our current work, we usually consider

building envelope, mechanical system (high-level), and lighting measures as well. Many mechanical system related energy efficiency measures are about equipment or system setup, but not on HVAC control which is very important

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    I used evolutionary algorithms in my Ph.D. research work. Evolutionary algorithms have a couple of salient features such as global search capability and easy to handle discrete variables. However, in comparison with deterministic numerical algorithms, evolutionary algorithms usually require many iterations with long computational time. But I believe that deterministic is more efficient, computationally. Many researchers combined deterministic and evolutionary algorithms together.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    No.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    For my PhD work, I used life cycle cost and life cycle environmental impact mostly. The prototype tool from my Ph.D. work also takes account of other criteria such as initial cost, operating cost, and operating energy consumption. Our current work as a major focus on onsite energy use reduction.

    b) **What kind of constraints do you set for optimization?**

    In addition to boundary constraints, we usually consider functional constraints such as initial cost limitation.

    c) **What kind of stopping criteria do you set for optimization?**

    I use evolutionary algorithm so I use the maximum number of generations as stopping criteria.

14. **How do you avoid the insolvable solutions space?**

    Normally, this is not a big problem if the inputs are well defined.

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

    I set a large penalty for the solution with failed simulation run.

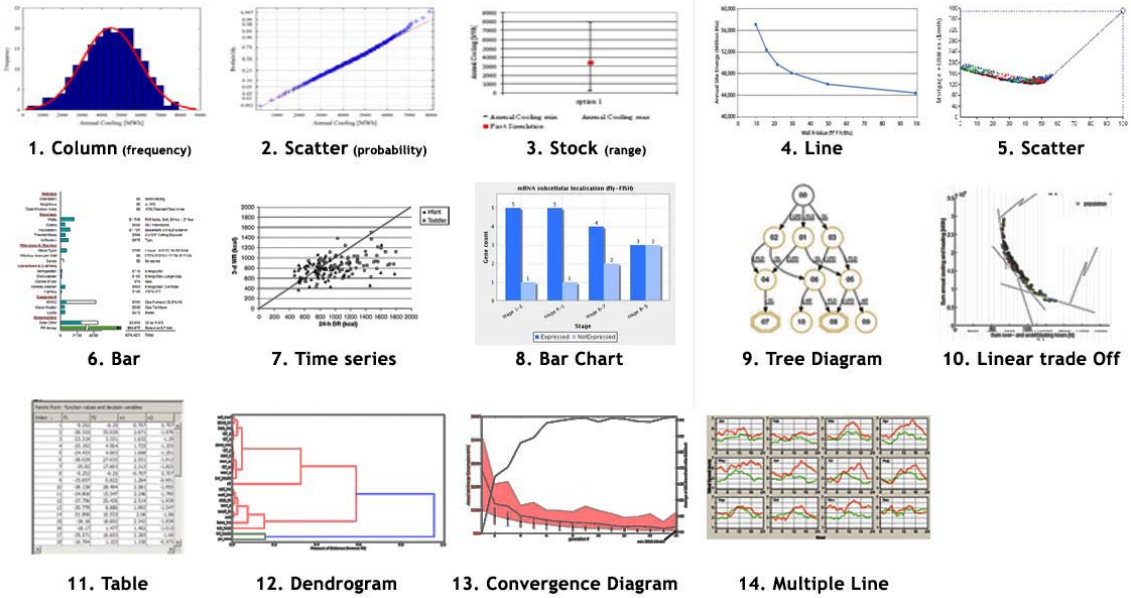
Output

16. **Do you have GUI for your own optimization tool?**

    No, in my research I had to post process the results. I don't see not having a GUI as a big problem for research. However, GUI becomes a very important feature if the optimization tool is to be used by designers.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

    Basically number 5 because I worked on multi objective optimisation with multiple criteria. The problem is that number 5 cannot give you the whole picture if you have more than two criteria. This graph includes a lot of solutions that you have to pick from the Pareto Front.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    There is a lot of opportunity in using optimisation. Currently, I think optimization is more a research topic than a design practice. This is probably because there is a lack of easy to use optimization tools available for building design. Just like building simulation which is rarely used by designers ten years ago but is getting more popular now, building optimization will get increasingly used in design years later.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I see it possible and ideally to fit into all stages of the design process. But optimization needs to meet the different needs and data availability for different design stages.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    Optimisation can be ideally used by both architects and engineers to explore different design possibilities. Maybe in the coming years this will happen but they must first know about simulation.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    This depends on the simulation program because simulation programs can have significantly different input requirement in terms of the number and the level of detail. The use optimisation in decision making process should evolve with the design process.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - The integration of optimisation with simulation it is difficult and requires time. This integration must be done in an intelligent way.

- Computation time: Designer want to get a fast feedback but if the optimisation will take some hours then no one will use that
- Multiple zones simulation and optimisation when involving geometry changes.
- Output, how to make GUI really very friendly and understandable by the designer.

23. **Would you use optimization tools if they were integrated unto an energy modelling tool?**
    Yes.
24. **Which tools would you recommend?**
    Depends on the problem and design. There are some good tools, but it might be difficult to recommend a certain tool. I usually recommend the DOE website.
25. **What features would you like to find in future tools?**
    - Easy to couple with different simulation programs
    - Easy for designers to define and modify optimisation problem variables
    - Easy to refine the optimization problem along with the design process
    - Computationally fast to facilitate interactive design optimization process
    - User friendly GUI

IEA Task 40 Interview with Michael Wetter, LBNL, USA

Interviewed: 11 January 2011 (MWetteratlbldotgov)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Building Technologies, Mechanical Engineering and Applied Math.
2. **Do you consider optimization aspects of NZEB design in work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, Uncertainty Analysis Optimization, others)**
   Yes. The main focus is to develop optimisation tools that other people can use. I also use them within research projects at LBL. I have been using optimisation and parametric studies but I am not working currently on sensitivity analysis.
3. **How many projects or case studies have you performed?**
   I have been working since 1997 on optimization, with several case studies.
4. **Approximately, how long does each project or case study take?**
   Typically one to two months for case studies. The actual development of the optimisation tool is ongoing since a few years.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   I use primarily GenOpt; I did use other tools as well.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes. I do it in Java. It is a mix of new optimisation methods as well as existing ones.

Methodology

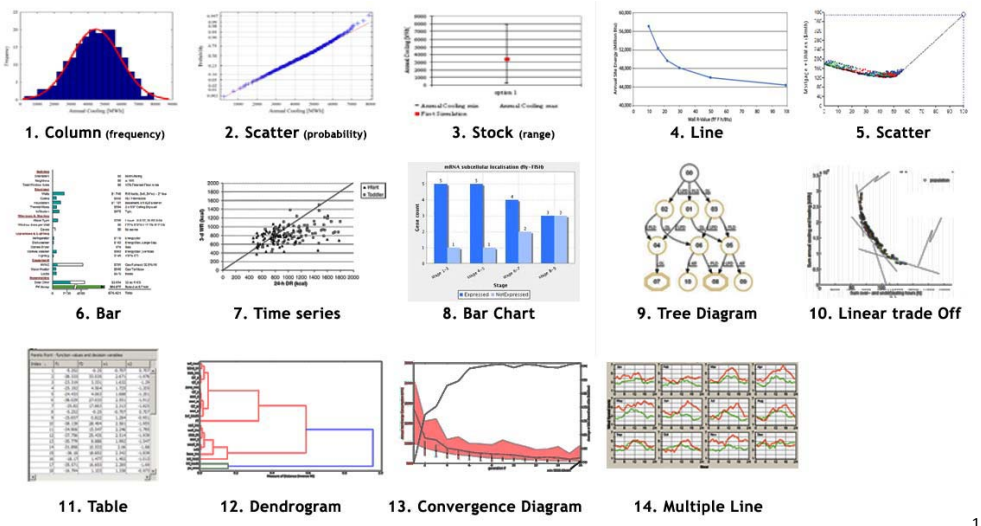
7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   Primarily commercial buildings in moderate and cold climate.
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Multizones.
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   Mainly control parameters but also building fabrics and geometry.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    Mainly deterministic because more is known about their convergence properties. Depending on the application, we use deterministic algorithms because they are generally faster, but in some

cases we use stochastic algorithms, or hybrid algorithms that combine stochastic and deterministic search.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    None of them
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    Yes, mainly sensitivity analysis to see what parameters are important and what parameters may be excluded from the optimization problem.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    Usually green house gas emission or source energy consumption. Most problems are single objective with constraints.
    b) **What kind of constraints do you set for optimization?**
    Usually thermal comfort, in some cases indoor air quality.
    c) **What kind of stopping criteria do you set for optimization?**
    It depends on the algorithm; some have them built-in stopping criteria, others run for a prescribed number of simulations.
14. **How do you avoid the insolvable solutions space?**
    I am not sure what "insolvable solution space" refers to. If you mean local versus global minima, then we use either multi-start optimization algorithms or population-based algorithms and configure them such that they do a global search.
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**
    It happens in very rare cases.

Output

16. **Do you have GUI for your own optimization tool?**
    GenOpt has a simple GUI that shows the process of the optimization. More sophisticated visualization is done in post-processing.
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**
    Primarily number 4 because we do single objective optimisation and we look at reduction in cost as a function of the dimensions.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Opportunities are across the whole building life cycle. During the early design, the detailed design, system sizing and during operation within model predictive control algorithms. So I think it is across the whole life cycle, as well as during product development of new building technologies.
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    Optimization can be used across all stages of the design process. In early design, it may be used to optimize the building design and thermal mass. During detailed design, other parameters may be varied such as control settings and HVAC equipment size. In particular for low energy technologies, building thermal mass becomes more important, and as this adds dynamics to the HVAC system response, the sizing problem becomes a dynamic problem that can effectively be solved using optimization.
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    Mainly mechanical engineers, but if optimization tools are integrated into design tools, they can be made accessible to architects as well. Let's say you have a CAD system and the architect can ask how big I can keep these south windows while avoiding overheating the room. This is an optimisation problem. So it is a matter of integrating the tools to make this technology accessible.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    You can do an optimisation, depending on the simulation program and problem, usually within a few hours on a single processor. If the optimization is deployed to a cloud computer, the computing time required to solve an optimization problem can be reduced from hours to minutes.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    - Lack of Integration of optimisation tools into design tools for early design
    - Simulation programs are not designed to be used with optimisation, i.e., they lack differentiability of the cost function with respect to design parameters. This prevents the use of many nonlinear programming algorithms that are known to be efficient and robust if the design parameter is large.
    - Lack of many building simulation programs to do a state initialization as needed when solving an optimal control problem
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes.
24. **Which tools would you recommend?**
    - N/a
25. **What features would you like to find in future tools?**
    - Stochastic optimisation
    - Mixed integer non-linear programming

IEA Task 40 Interview with Jonathan Wright, Loughborough University

Interviewed: 16 May 2011 (J.A.Wrightatlboro.ac.uk)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   Engineering. Professor of building optimisation.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   My research is concerned with building optimisation. We are studying various building optimisation problems ranging from space layout planning through to routine parametric optimisation and some sensitivity and uncertainty analysis. We are also looking at the relationship between sensitivity analysis and optimisation.
3. **How many projects or case studies have you performed?**
   In the order of 10.
4. **Approximately, how long does each project or case study take?**
   Anything from a week to a year but our work is research and not design. Some of the problems we're looked at are not routine optimization problems and are being studied by PhD students. We have not been involvement in design practice to date.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We use our own tools written in Java. We have some generic tools but in some cases we write code that is specific to the particular project. The generic tool is similar to GenOpt in that it is a text-based input/out interface. Nearly all of the algorithms that we use are derived from evolutionary algorithms.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes, we have written a number of algorithms that are specifically designed to solve a particular problem; the algorithms have been implemented in both "C" and Java.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
   In research we have run problems for various climates including USA continental climate, UK temperate climate, and Malaysian tropical climate. The buildings are mainly offices or

institutional. I think the only category that you have listed that we have never investigated is retail.

8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
   Both single and multi-zone, with multi-zone being for a buildings between 5 and 30 zones The choice between single and mulit-zone depnds on what you are studying or trying to optimize, and whether modelling it as a single zone is valid (if simulating the performance of a single zone is valid, then its probably safe to use a single zone for the optimization).
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
   Most of what we are doing is parametric optimisation so the variable are window geometry, control set points, choice of construction materials, HVAC system types etc.
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
    Evolutionary algorithms. The big breakthrough for me with evolutionary algorithms was that I was trying too solve some highly constrained HVAC optimisation problems and conventional algorithms just couldn't do it. Whereas a simple Genetic Algorithm solved the problem with relative ease. Evolutionary algorithms are adaptable and very powerful in finding good solutions. It is difficult to know whether they have found global minima, but this is not a critical flaw so long as you can measure the improvement in the optimality of a solution against a base case
    It might also be argued that the notion of trying to find an optimum nonsense because there is so much uncertainty in the modelling that you can't possibly say your simulation relates to reality. It's also the case that optimization is not so much about finding the "best" solution, but as much about exploring the design space for alternative solutions. Evolutionary algorithms are robust in exploring the search space for a wide range of building optimization problems. Unlike many other conventional or heuristic algorithms, Evolutionary Algorithms are also easily adapted to enable them to solve a particular optimization problem more effectively.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
    No.
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
    We have a project that is looking to the kind of relationship between the two. If you use an evolutionary algorithm you often end up with a whole set of solutions that you can analyse to find some relationship between the variables and objective functions. This is particularly the case for multi-objective optimization, which naturally produces a set of optimum solutions that can be analysed.
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
       Energy and capital cost and thermal comfort and carbon emissions.
    b) **What kind of constraints do you set for optimization?**
       Thermal comfort, indoor air quality, sometimes capital cost is a constraint rather than an objective. For some problems it can be a whole range of problem specific constraints. For instance in layout space planning you have got a constraint on travel distance between rooms. It depends on the problem.
    c) **What kind of stopping criteria do you set for optimization?**

We use the number of unique function evaluations as a stopping criteria, as the highest computation load is associated with the running the simulation. The maximum number of function evaluations is set from initial trails run on particular optimisation problems.

14. **How do you avoid the insolvable and infeasible solutions space?**

This comes back to the power of evolutionary algorithms the idea that you can control exploration versus exploitation. Exploitation means that the search is biased towards the current set of solutions so they have a big impact on next generation. While exploration means that you are going to explore more of the search space for longer. Evolutionary algorithms allow control of that balance., so that more exploration can be performed of highly constrained search spaces. The flexibility of Evolutionary Algorithms in terms of the forms of their operators means that several methods have been developed for handling infeasible solutions (ranging from simply rejecting them through to allowing the best of the infeasible solutions to be used in the production of the next generation of solutions).

15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

Evolutionary Algorithms work on a population of solutions, and so, provided some solutions in the population result in successful simulation runs, you can simply reject the solutions having a failed simulation run. Evolutionary Algorithms can be surprisingly robust to high simulation failure rates.

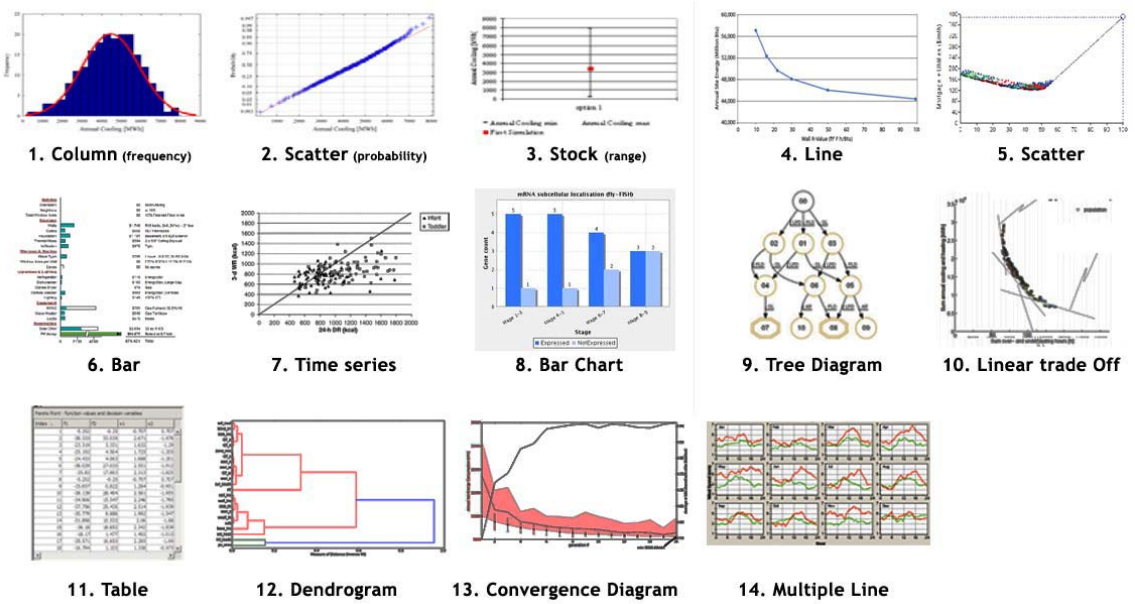
Output

16. **Do you have GUI for your own optimization tool?**

No. Currently we have a command line but we have plans for that.

17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**

Scatter chart (5), line (4), stock (3), frequency (1), scatter (2), table (11), convergence (13), and multiple line (14). .



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    The rise of simulation has been driven by many things, including government policy that pushes the design of low carbon buildings. At present, any increase in the use of optimization will be driven by the extent to which aids design decision making. In this respect, one of the most powerful forms optimization is multi-object optimization, since this gives you a set of solutions that lie on the trade-off between two or conflicting design objectives. The trade-off can be used to explore the impact of say of less capital investment on the increase in carbon emissions (this kind of information being useful in decision making).
19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
    I think it is the all stages but particularly the early design phases where there is greater flexibility to influence the design and therefore performance of the building
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
    I think ultimately all of them. My view is that optimisation is about presenting design alternatives to the designer regardless of who they are. So it might be that the architect has a different set of tools and it is a different optimisation methodology but I don't see any reason why they should be excluded from using optimisation. They use modelling in some form or another now so, if they use modelling then they can use optimisation. It might be a tool that allows them to explore shape, for example.
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**
    From a practice point of view you need a commercial tool with integrated simulation-optimisation that allows seamless link between the simulation model and the optimization process. Without this, the time and knowledge required implementing separate simulation models and optimization algorithms will limits the use of optimization in practice

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
    The biggest obstacle, I think in practice, is the users understanding of the optimisation process. So there is a big educational need before this takes off routinely. Computation time is also long and this might well inhibit the initial take-up of optimization in practice. The optimization processes also magnifies the idea of "rubbish-in-rubbish-out" since rather than simulate a single design solution, the errors or inaccuracies in a simulation are exposed across a wide range of the design space. This may lead to a need for better education and improved user interfaces for simulation, as well as more work on the uncertainty associated with simulation models.
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Perhaps, but that depends on the extent to which they can be used to investigate a particular research question.
24. **Which tools would you recommend?**
    The main resource that has been used is Genopt.
25. **What features would you like to find in future tools?**
    The holy grail of optimisation would be to have machines and simulations that run fast enough that you can look at you results in an interactive way. If that can be achieved, then the designer

can act to influence the direction of the optimization (shift the search to a more interesting region of the design space). At present, the designer it almost the case that the design has to wait and inspect the solutions when the optimization is complete; if the solutions do not include any that are desirable, the design has to re-define the scope of the search and re-run the optimization.

IEA Task 40 Interview with Yi Zhang, De Montfort University, UK

Interviewed: 23 May 2011 (yizhangatdmu.ac.uk)

Background Information:

1. **What is your major field of study (engineering, architecture, computer science other)?**
   My background is in building services engineering and I am working as a senior research fellow in the field of energy efficiency in buildings.
2. **Do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
   Yes, I have been using optimisation for quite a few years, actually since the start of my PhD in 2000. I mainly use evolutionary algorithms on building design problems, though not particularly on zero carbon or zero energy buildings. I use optimisation on various aspects related to low energy building design, such as HVAC systems, thermal comfort, lighting or controls. Evolutionary algorithms is my choice of approach. I only started to do studies on sensitivity and uncertainty analysis recently, because we have now a very good tool to do this kind of studies.
3. **How many projects or case studies have you performed?**
   Hmm… we tried optimisation on many things. But in terms of published case studies, the number is very limited. I think I have five to ten case studies worth noting.
4. **Approximately, how long does each project or case study take?**
   It varies a lot. Some cases are very simple and optimisation can finish in minutes. Others can take weeks to finish on PC clusters.
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
   We tried various tools, including the Matlab toolbox, Genopt and other evolutionary algorithms packages such as ECJ or GAlib, if you heard about them. They are source code packages; so if you know programming, you can develop your own code. There are of course many other packages available. Simulation tools I used include Matlab/Simulink, Ansys CFX, Radiance, IESD-Fiala model, and of course our own simulation models. For building simulation, I am using EnergyPlus at the moment.
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**
   Yes and no, depends on what you mean with “my own algorithm”. Most algorithms I used have been invented and reported by others. But I have my own implementation, or my own evolutionary algorithms package. It is written in Java.

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**

   Mainly office buildings I would say, because my field is in building services engineering and residential buildings don't have HVAC systems. However, we started looking at residential buildings as well. We have not studied retail, industrial or other types of buildings. The buildings are mainly in the UK.

8. **How many zones do you address when running optimizations? (Single zones – Multizones)**

   Not many, two or three because the buildings itself hasn't be the main interest of my work. So we focus on systems. We are interested in multi-zone models cause it presents a bigger challenge to system design.

9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**

   Well we haven't done geometry or climate. I tried a couple of envelope and found it a relatively easy issue. My main interest is in coupled HVAC systems and ventilation and controls and daylighting as well.

10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**

    I have mainly used evolutionary algorithms because they are robust and generic. So whatever problem you have the algorithm is likely to find a good solution. This is not true or possible with deterministic search approaches. They are only suitable for certain parts or types of the problems. If the design problem is, for example, multi-modal then those (deterministic) algorithms will not perform well. You have to know the nature of your problem and do a lot of preparation, such as sensitivity analysis on the design parameters, to understand the characteristics of your problem before choosing a suitable algorithm. On the other hand, if you want to do it with evolutionary algorithms, you are guaranteed to get solutions.

11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**

    No, I am not familiar with these approaches.

12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**

    Well, I haven't done any sensitivity and uncertainty analysis in conjunction with the optimisation studies. However, I think they need to be considered carefully, as a method of understanding the problem and its solution space. This may guide the selection of optimisation algorithms. Sensitivity analysis may be used to test the optimality of the solutions that the algorithms have found. Unfortunately, I have not done these, and do not know if there are established approaches to use UA/SA with optimisation.

    Do you think both sensitivity and uncertainty analysis should be done?

    It is problem dependent, I guess. I would look at both on a case-by-case basis. A prior UA and/or SA may be more important to deterministic approaches, than to stochastic, population-based approaches. Time is apparently another limiting factor.

13. **Under which setting you run you optimization what is your methodology?**

    a) **What kind of objectives do you set for optimization?**

    So far I have only done single objective optimisation, mainly on energy efficiency, and sometimes on thermal comfort, another area of my research interests. I hardly did any cost analysis. However, at the moment we are developing some multi objective algorithms with a commercial partner to incorporate cost, energy efficiency, carbon emissions and comfort.

    b) **What kind of constraints do you set for optimization?**

We use mainly comfort as a constraint obviously you can use it as a secondary objective or maybe as the first objective as well. The other constraints are physical constraints like the feasible operating conditions of buildings or building systems.

c) What kind of stopping criteria do you set for optimization?

I normally use a fixed number of generations as the stopping criterion.

14. How do you avoid the insolvable solutions space?

Well, I am not familiar with the concept of insolvable solutions space. If the evolutionary algorithms fail to find a solution for your problem, it is more likely that you haven't formed the problem (or defining the solution space) properly in the first place. Check typos or debug your code is my suggestion.

15. How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)

This is one of the reasons why I choose evolutionary algorithms - they are by nature more robust in such situations. Individual simulation failures would not impede the progression of the whole population. The stochastic nature of the algorithm will help explore unknown solution space, so it is rare that the algorithm gets stuck because of failed simulation runs.

Nowadays simulation software is fairly good. I am using EnergyPlus. Most simulations finish without problem unless there is a syntax problem in the model. But if it happens, the algorithm simply throws the individual case away and carries on. You would not be so lucky if you are using a deterministic algorithm.

Output

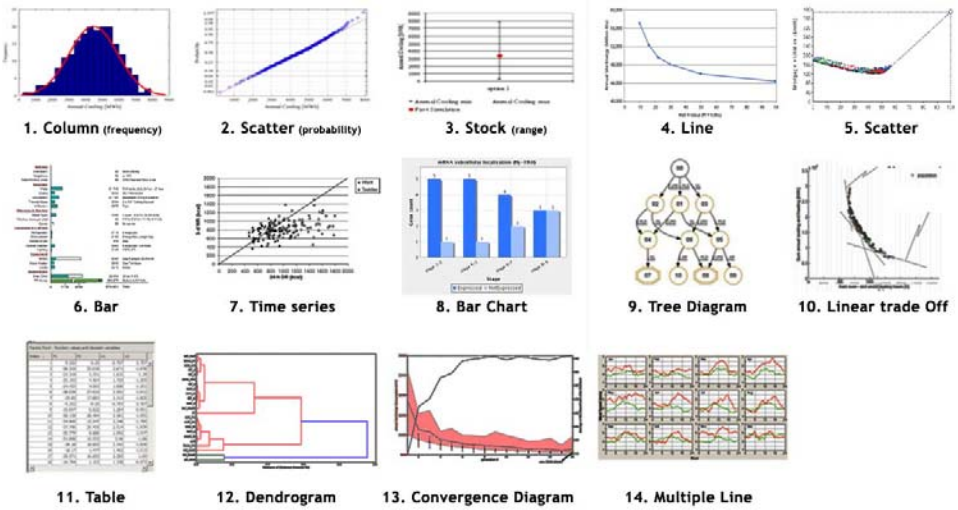
16. Do you have GUI for your own optimization tool?

My own evolutionary algorithms package has a GUI showing the progress of optimisation itself rather than the results.

17. Which kind of output analysis visualisation did you do using optimisation tools? (1-14)

I use line charts 4 and scatter plots 5 most frequently.

I think if there is a tool that can give you a full range of analyses of the results in the form of various graphs, it will be great.



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Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process?**

    There many opportunities for this kind of integration. It is actually happening. There are ongoing projects that involve academics and commercial partners working on integrating optimisation into building design tools. For example, we (De Montfort University) are working with DesignBuilder Software to implement evolutionary algorithms in their product. There are other groups doing similar things as well. This is happening because it is necessary. Users are using a design tool to find good solutions. If optimisation techniques are embedded in the design tools, user will use them. I would think they should be used throughout the life cycle of buildings.

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

    Like building simulation itself, optimisation can be applied to any design stage. This is only limited by the ability to obtain an appropriate model at the stage in question. In theory, optimisation should start from the very early stage of the design process. For example, on a sketch one can start optimising the orientation, geometry and facades/fenestration to maximize natural lighting. It would not be possible to optimise energy consumption in the conceptual design stage, however, as the building energy performance depends as much on the decisions made at the detailed design stage and in operation, as on conceptual design options. Each design stage would have its own optimisation problems.

20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**

    One tool for all does not really exist. Apparently a good software tool should be designed to meet the requirements of its target users. The challenge for tool developers is to understand the problems the targeted users have. I think engineers, consultants and architects are better qualified to answer this question.

21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

    I am pretty confident that all stakeholders want their buildings to be optimised. Whether or not they will trust decision making to a box under the desk is a different question. In order for optimisation to assist decision making, the process and the results have to be well presented and understood, so that the users can gain confidence from the information. Very few professionals will rely on algorithms without knowing how they work. So, in order to integrate optimisation into decision making, the key barrier is informing the users of what is going on and why the optimised solution is better than what they can achieve by other means. The optimisation tools have to deliver the right information to the users.

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**

    There are two main obstacles. The first one is the learning curve and effort of using optimisation techniques. It takes quite some time to understand an optimisation algorithm and to set up a problem. It takes even longer to make the algorithm work 'properly' with problems at hand. And before all these, the user has to know what optimisation can be useful for in the first place. The second obstacle is computing time. Although you can say that the user can set up an optimisation before taking off for the day, and check the results the next morning, (this is how

researchers deal with it,) it would be unacceptable in practice. The computing time is a great barrier.

23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
    Yes, if it works I think many people would like to use it.
24. **Which tools would you recommend?**
    There are not many tools available and every tool has its own advantages. For a start Matlab would be a good candidate. It has a good user interface that can do all sorts of things, and it is well documented. It is a good starting point for learning optimisation.
25. **What features would you like to find in future tools?**
    Optimisation in future tools should be a click-button function. The user can choose from a list of typical design problems for that design stage, click a button, and wait for the algorithms to find a best solution. If the search takes time, the user should be able to interact with the process, check progress, explore intermediate solutions, and adjust the task on the fly. Comprehensive information of the solutions should be presented to help the user understand the merits and limitations. I truly believe a tool like such will be developed in the near future.

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Appendix A: Questionnaire

Integration of Optimization Techniques for Zero Energy Buildings (Interview)

Given the implication of designing **Net Zero Energy Buildings** (NZEBs), which involves complex passive and active design strategies, the use of optimization techniques is becoming more essential. Therefore, this structured interview aims to assess gaps, needs and problems considering the integration of optimization techniques to support the design of NZEBs. This work is part of the International Energy Agency (IEA) Task 40: Towards Net Zero Energy Buildings Subtask B.

The audience of this interview is building designers and building energy specialist concerned with the implementation and integration of optimization techniques for high performance buildings.

Background Information:

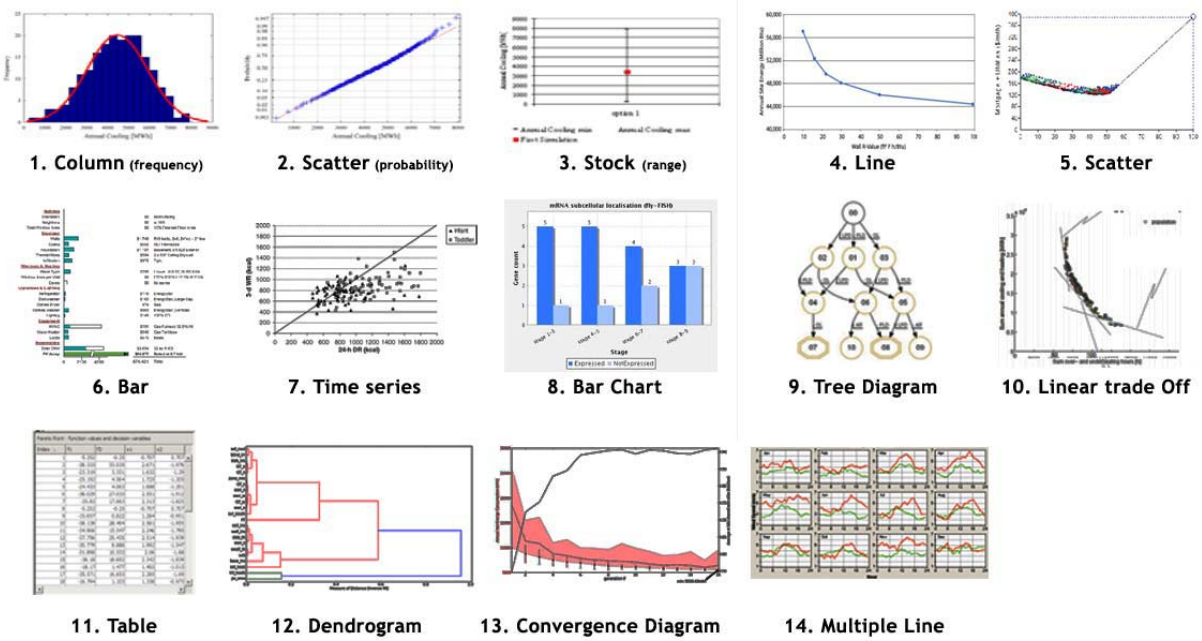
1. **What is your major field of study (engineering, architecture, computer science other)?**
2. **How do you consider optimization aspects of NZEB design in your work? Describe the methodology you use while approaching a building optimization problem. (Sensitivity Analysis, uncertainty analysis, optimization, others)**
3. **How many projects or case studies have you performed?**
4. **Approximately, how long does each project or case study take?**
5. **What kind of tools do you use for optimisation (MATLAB, GENOPT, others)? To which simulation tool do you couple it?**
6. **Have you developed your own optimisation algorithm? (if yes, which programming language)**

Methodology

7. **Which building typologies have you used optimization for and in which climates? (Residential, Offices, Retail, Institutional)**
8. **How many zones do you address when running optimizations? (Single zones – Multizones)**
9. **What kind of design variables do you set for optimization? (Geometry, Climate, Envelope, HVAC systems, Solar Systems, Multizone air flow and ventilation, Occupant Behaviour, Advanced Controls, daylighting, PV, renewable systems etc.)**
10. **What kind of optimisation algorithm do you use? (deterministic: e.g , evolutionary: e.g) and for which reason you use a or b?**
11. **Do you use neural network or fuzzy or multi-dimension interpolation during post processing, and why?**
12. **Do you perform a sensitivity and/or uncertainty analysis in addition to your optimization study, when and how?**
13. **Under which setting you run you optimization what is your methodology?**
    a) **What kind of objectives do you set for optimization?**
    b) **What kind of constraints do you set for optimization?**
    c) **What kind of stopping criteria do you set for optimization?**
14. **How do you avoid the insolvable and infeasible solutions space?**
15. **How do you avoid the failed simulation runs? (How do you solve the interruption problem of simulation)**

Output

16. **Do you have GUI for your own optimization tool?**
17. **Which kind of output analysis visualisation did you do using optimisation tools? (1-14)**



1 Optimal Solution (Fitness), 2 Solutions Probabilities, 3 Solution range, 4 Solution line, 5 Solution Space 6 Parametric Weights, 7 Time series, 8 Solution Comparison, 9 Solution Tree (Dendrom) (© Elaine Hale), 10 Linear Trade Off (©Christina Hopfe), 11 Table, 12 Dendrogram (clustering of variables) (Bucking), 13 Fitness and average Fitness, 14 Thermal contour plot

Integration with Design Process

18. **What opportunities you see in integrating optimisation techniques in NZEB design process? How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**

19. **How does it fit into the design process? At which stage of the building design process should optimisation techniques be used?**
20. **Who will be the user group? Should optimisation techniques used by mechanical, simulation consultant, engineers or architects tool?**
21. **How can it be integrated into the decision making? How should optimisation become more practically applied in early design phases?**

Developers: Shortcomings

22. **What the major practice obstacles of integrating optimization techniques in NZEB design?**
23. **Would you use optimization tools if they were integrated into an energy modelling tool?**
24. **Which tools would you recommend?**
25. **What features would you like to find in future tools?**