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MOBO a New Software for Multi-Objective Building Performance Optimization

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Multi-Objective Optimization

MOBO can be used to optimize problems with *n* objective function(s) and *J+K* constraint function(s)

$min\ (f_1(x), f_2(x), \ldots, f_n(x))$ such that
$g_i(x) \leq 0\ (i=1,\ldots J)$ and
$h_j(x) = 0\ (j=1,\ldots K)$

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MAIN FEATURES OF MOBO

- MOBO is a generic freeware able to handle single and multi-objective optimization problems with continuous and discrete variables and constraint functions
- MOBO can be coupled to many external (simulation) programs
- It has a an extendable library of different types of algorithms (evolutionary, deterministic, hybrid, exhaustive and random)
- It is able to handle multi-modal functions and has automatic constraint handling
- The input is fed by a GUI for defining the optimization problem
- The user can write the input by algebraic formulas using standard symbols
- The output can be viewed by two graphs that show the progress of the optimization
- Allows parallel simulation
- Portability

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ERRORS IN USERS INPUT ARE CHECKED INTERACTIVELY

ALGORITHMS IN MOBO

	PROBLEM					VARIABLES		
Algorithm	Single	Multi-	Constrained	Multi-modal	Automatic Constraint handling	Discrete	Continuous	Parallel Computing
Binary NSGA-II	x	x	x		x	x	x	x
BINARY Pareto Archive NSGA-II	x	x	x		x	x	x	x
Binary OMNI-Optimizer	x	x	x	x	x	x	x	x
Real Coded NSGA-II	x	x	x		x		x	x
Real Coded Pareto Archive NSGA-II	x	x	x		x		x	x
Real Coded OMNI-Optimizer	x	x	x	x	x		x	x
Hooke-Jeeves	x		x		x		x	
Hybrid Algorithm	x		x		x	x	x	x
Brute-Force	x	x	x	x		x	x	x
Random Search	x	x	x	x		x	x	x

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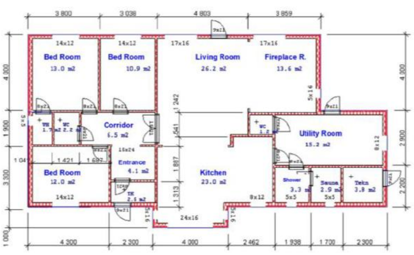
EXAMPLE 1



Design variables of the optimization problem

Design Variables	Type	Min. Value	Max. Value
Additional insulation thickness in external walls (m)	Continuous	0	1
Additional insulation thickness in roof (m)	Continuous	0	1
Additional insulation thickness in floor (m)	Continuous	0	1
Window's *U*-values (W/m^2K)	Discrete (two options)	1	1.4
Heat recovery efficiency (%)	Discrete (two options)	70	80

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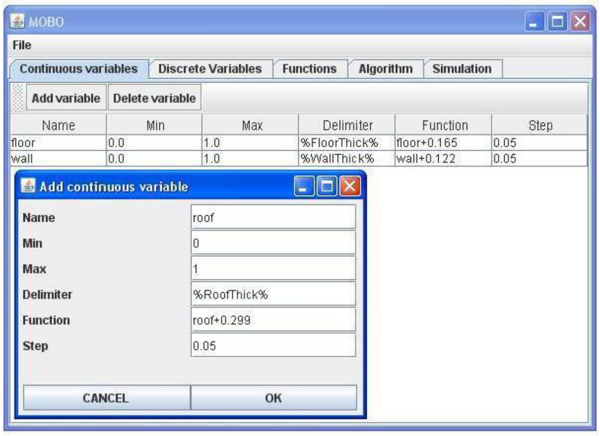

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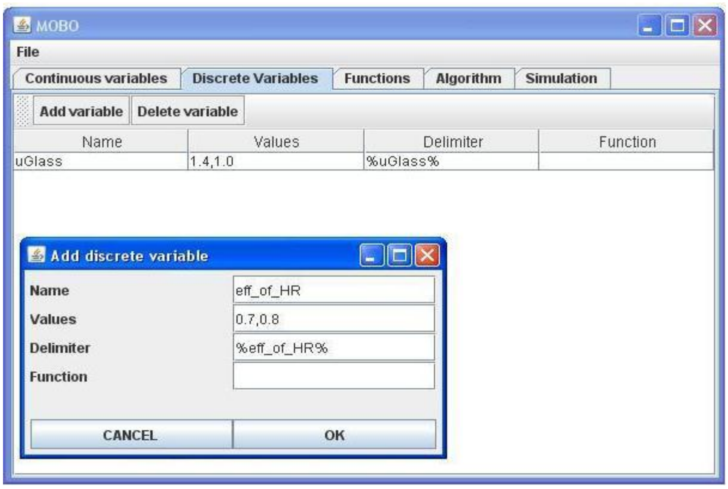

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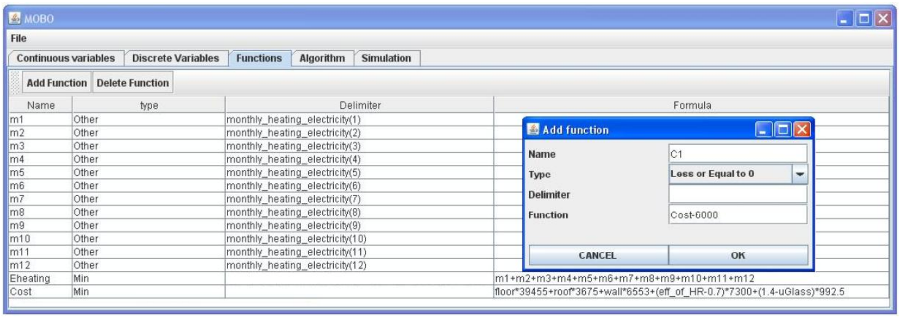

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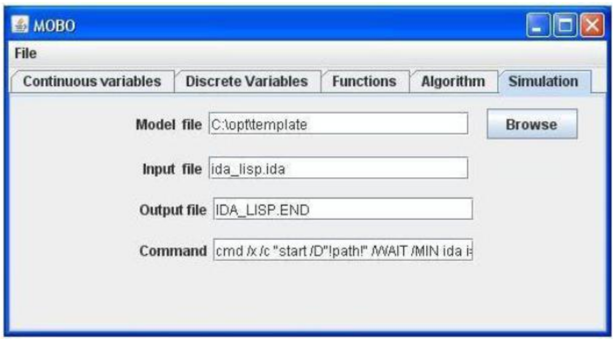

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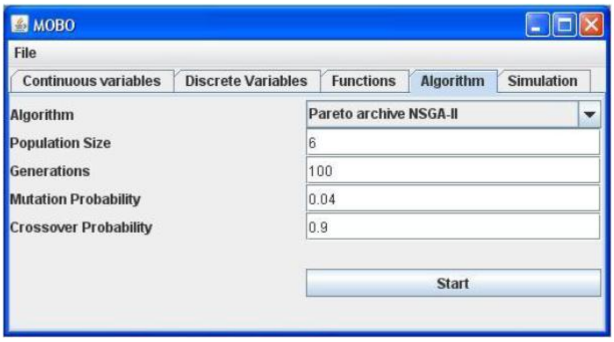

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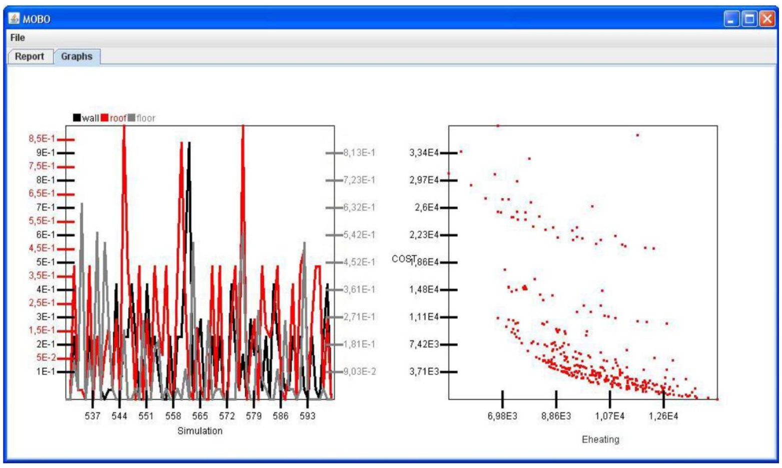

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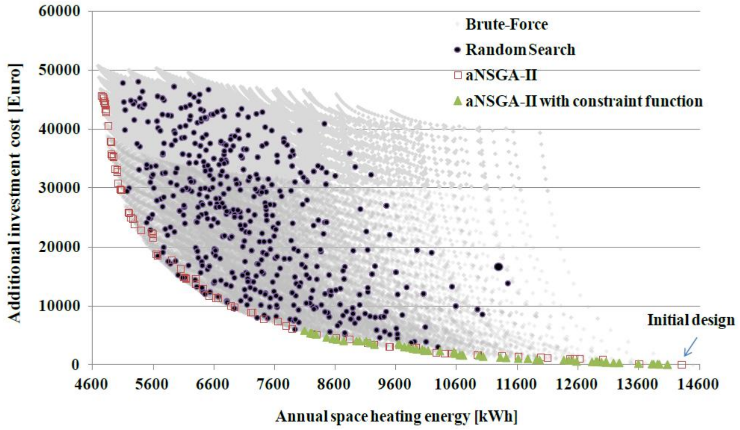

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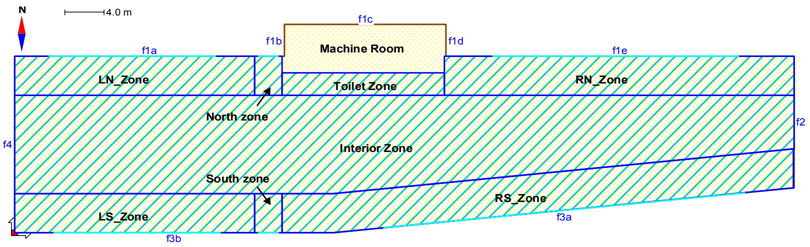
Example 2: Optimal Solutions for High Thermal Comfort in Office Building



Two zones
Cooling beams for cooling (chiller)
Water radiators (district heating)
AHU (with cooling and heating coils) supply and exhaust fans

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OBJECTIVES

optimal design that should satisfy minimization of three objectives

- ***f1 primary energy consumption***
- ***f2 thermal comfort level deviations***
- ***f3 cooling beam capacity***

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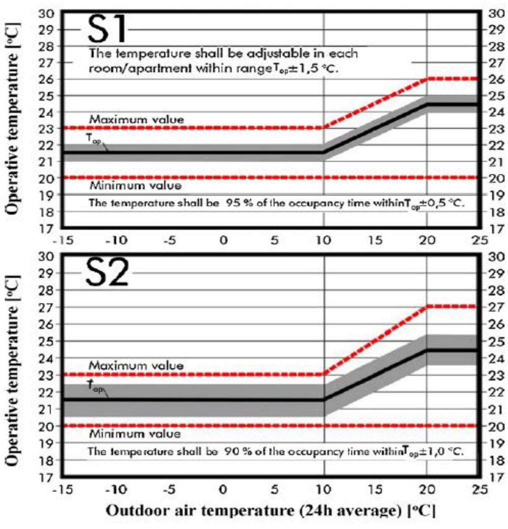

Fig. 1. The set-point profile, minimum and maximum limits according to the Finnish Classification of Indoor Climate 2008 [25].

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DESIGN VARIABLES

- Cooling beam operating temperatures
- Water radiator night set-back temperatures
- Night cooling: set temperatures and operating times
- Window Shading
- Ventilation air supply temperature
- U-glazing

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24 Design Variables, 4 pre-process functions and 8 input functions

Table 2
Design variables and their lower bounds (*LB*) and upper bounds (*UB*).

Design variables		X	Description	First step *LB*	First step *UB*
AHU	Supply air temp. profile	X_1	T_s at ODT $\le$ 16 [°C][a]	16	24
		X_2	T_s at ODT $\ge$ 24 [°C][a]	16	24
	Night ventilation control strategy (NV)	X_3	NV is enabled if ODT $\ge X_3$ [°C]	5	20
		X_4	NV is enabled if $T_{exh} - \text{ODT} \ge X_4$ [°C]	1	3
		X_5	NV is enabled if $T_{exh} \ge X_5$ [°C]	18	24
		X_6	T_s drop X_6 degree during NV [°C]	5	10
		X_7	NV is not enabled X_7 [h] before the occupation	0	7
		X_8	NV is not enabled X_8 [h] after the occupation	0	6
North Office	Cooling beam	X_9	Max. power of the cooling beam [W]	200	600
		X_{10}	dT(coolant) at max power [°C]	2	5
		X_{11}	dT(zone air – coolant) at max power [°C]	6	9
	Water radiator	X_{12}	Night set-back temperature [°C]	18	21
		X_{13}	Set-point temperature [°C]	20	21.5
		X_{14}	Control band [°C]	0.3	3
	Window	X_{15}	Window *U*-value [W/(m² K)]	1	2.5
		X_{16}	Internal shading darkness	Light	Dark
South Office	Cooling beam	X_{17}	Max. power of the cooling beam [W]	200	600
		X_{18}	dT(coolant) at max power [°C]	2	5
		X_{19}	dT(zone air – coolant) at max power [°C]	6	9
	Water radiator	X_{20}	Night set-back temperature [°C]	18	21
		X_{21}	Set-point temperature [°C]	20	21.5
		X_{22}	Control band [°C]	0.3	3
	Window	X_{23}	Window *U*-value [W/(m² K)]	1	2.5
		X_{24}	Internal shading darkness	Light	Dark

ODT: outdoor air temperature; T_s: supply air temperature set-point; T_{exh}: exhaust air temperature from the modelled floor.
[a] A linear relation is assumed between T_s and ODT at $16 \le \text{ODT} \le 24$.

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MOBO

File View

Continuous variables | Discrete Variables | Functions | Algorithm | Simulation

Add variable | Delete variable | Modify variable

Name	Min	Max	Delimiter	Function	Step
T_low	16.0	24.0	%T_low%		4.0
T_high	16.0	24.0	%T_high%		1.0
T_NV_amb	5.0	20.0	%T_NV_amb%		3.5
T_NV_add	1.0	3.0	%T_NV_add%		3.5
T_NV_ret	18.0	24.0	%T_NV_ret%		1.5
T_NV_addset	5.0	10.0	%T_NV_addset%		1.25
NV_A	0.0	7.0	%NV_A%	7-NV_A	0.05
NV_B	0.0	6.0	%NV_B%	18+NV_B	0.05
CBpower_N	200.0	600.0	%CBpower_N%		100.0
dTliq_N	2.0	5.0	%dTliq_N%		0.05
DTa_N	6.0	9.0	%DTa_N%		0.5
NSB_N	18.0	21.0	%NSB_N%		0.5
WRSP_N	20.0	21.5	%WRSP_N%		0.05
WRDB_N	0.3	3.0	%WRDB_N%		0.05
H_O_N	1.0	2.5	%H_O_N%		0.05
M_G_N	0.0	0.15	%M_G_N%	0.46-M_G_N	0.01
CBpower_S	200.0	600.0	%CBpower_S%		50.0
dTliq_S	2.0	5.0	%dTliq_S%		0.5
DTa_S	6.0	9.0	%Dta_S%		0.05
NSB_S	18.0	21.0	%NSB_S%		1.0
WRSP_S	20.0	21.5	%WRSP_S%		0.05
WRDB_S	0.3	3.0	%WRDB_S%		0.4
H_O_S	1.0	2.5	%H_O_S%		0.05
M_G_S	0.0	0.15	%M_G_S%	0.46-M_G_S	0.01

Input Functions

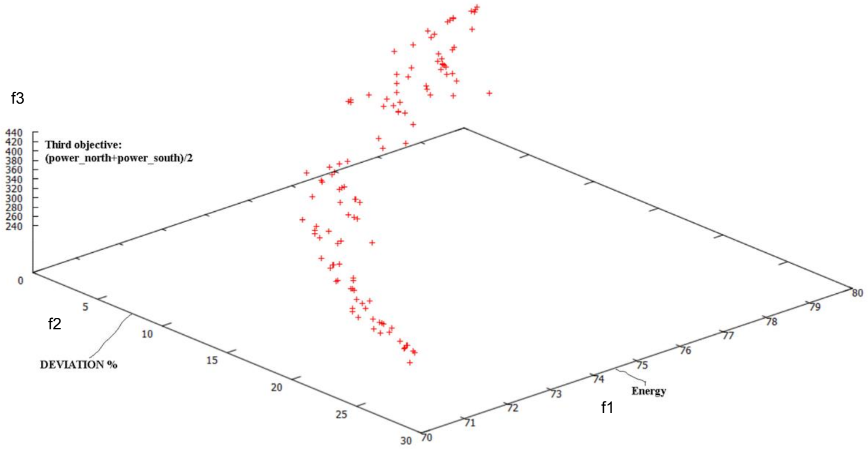
MOBO

File View

Continuous variables | Discrete Variables | Functions | Algorithm | Simulation

Add variable | Delete variable | Modify variable

Name	Values	Delimiter	Function
M_T_N	0,1	%M_T_N%	0.04+M_G_N
M_T_S	0,1	%M_T_S%	0.04+M_G_S
Mw_N	0,1	%Mw_N%	CBpower_N/(dTliq_N*4187)
K2_N	0,1	%K2_N%	CBpower_N/(2*pow(DTa_N,1.5))
K1_N	0,1	%K1_N%	CBpower_N*0.25/(2*pow(DTa_N,1.5))
Mw_S	0,1	%Mw_S%	CBpower_S/(dTliq_S*4187)
K2_S	0,1	%K2_S%	CBpower_S/(2*pow(DTa_S,1.5))
K1_S	0,1	%K1_S%	CBpower_S*0.25/(2*pow(DTa_S,1.5))



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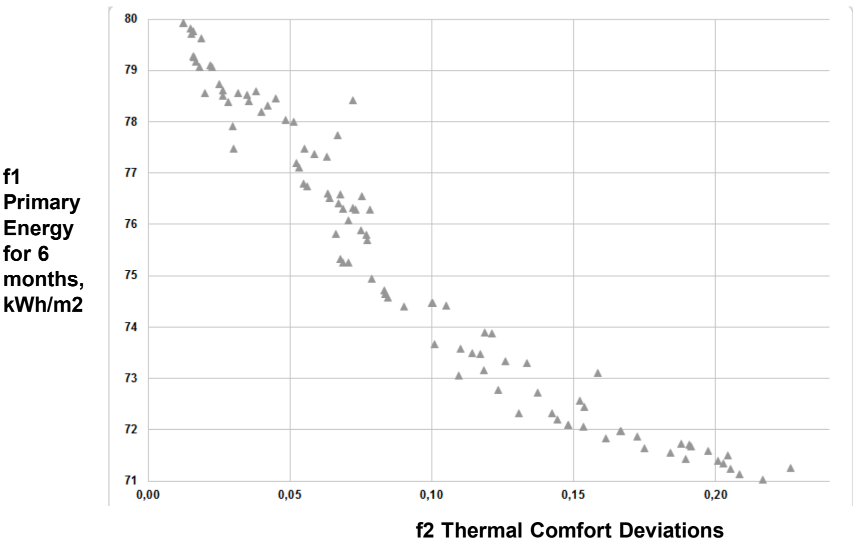

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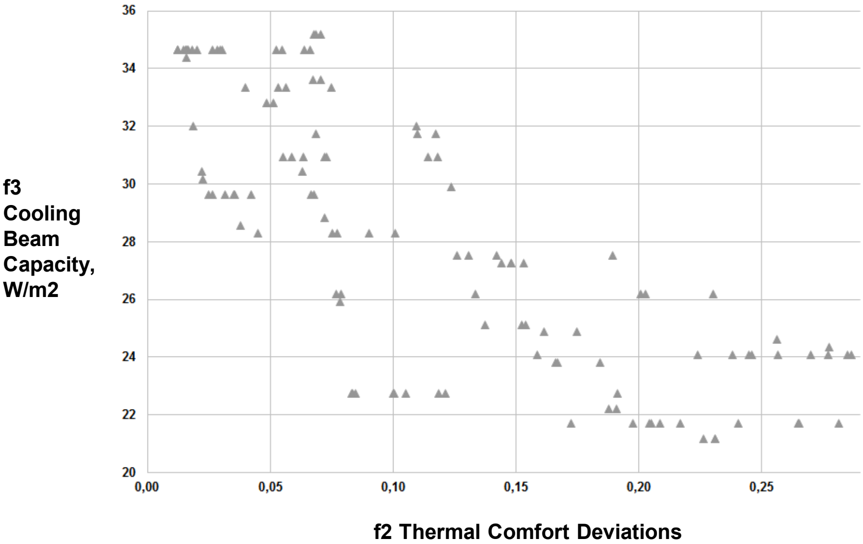

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13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28

MOBO A NEW SOFTWARE FOR MULTI-OBJECTIVE BUILDING PERFORMANCE OPTIMIZATION

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ABSTRACT

This paper introduces a new software developed for building performance optimization. MOBO is a generic freeware able to handle single and multi-objective optimization problems with continuous and discrete variables and constraint functions. It can be coupled to many external (simulation) programs. It has a library of different types of algorithms (evolutionary, deterministic, hybrid, exhaustive and random), and is able to handle multi-modal functions and have automatic constraint handling. The input is fed by a GUI. The user can write the input by algebraic formulas using standard symbols. The output can be viewed by two graphs that show the progress of the optimization. A beta version of MOBO is available for download and use.

INTRODUCTION

By building optimization, it is possible to find optimal values of decision variables, among huge numbers of possible combinations, which are able to achieve defined conflicting objective functions and at the same time satisfy specified constraint functions. Various decision variables can be considered in the building envelope, the heating, ventilating and air conditioning (HVAC) systems, the centralised/on-site energy generation systems etc. Examples of the objectives are: minimization of environmental impacts (energy consumption, carbon emissions etc.), cost (investment cost, operating cost, life-cycle cost), equipment size (energy generation units, HVAC system etc.), and/or maximization of indoor air quality, energy efficiency, etc. These can be achieved individually, as single objectives, or simultaneously, as multi-objective optimization. The constraint functions may indicate satisfying, or not violating, different criteria (e.g. thermal comfort level, total investment cost limit, primary energy limit etc.).
Currently, there are many building optimization tools available with different features. However, we think that there is still a need for a new tool that should be a generic freeware and can fill the shortages recognised in the available tools. These were our main motivations for developing MOBO, a Multi-

REVIEW

This section reviews some available optimization tools that have been used for building performance optimization. Table 1 gathers some main features of the reviewed tools. These tools can be classified into two categories: customized and generic tools.

Customized optimization tools

Opt-E-Plus, GENE_ARCH, BEopt™, TRNOPT, MultiOpt2, and jEPlus+EA are examples of tools customized mainly for building energy performance optimization. These tools are combinations of optimization algorithms/approaches and building performance simulation engines.
In **Opt-E-Plus** (Ellis et al., 2006), EnergyPlus simulation engine was coupled with a number of optimization strategies. Opt-E-Plus is a collection of input and output files, system directories, and computer routines that use an XML data model to transfer information among its various components. It allows distributed programming and supports selection of automation and optimization strategies. Opt-E-Plus doesn't support multidisciplinary optimization and the visualization of its tradespace is limited (Flager et al., 2008).
GENE_ARCH (Caldas, 2006) has scalable geometry generation functionality and good visualization capabilities. It is customized to couple DOE2.1E for building performance simulation and genetic algorithms for optimization. GENE_ARCH was used to find energy-efficient architecture solutions (Caldas, 2008 and 2011).
BEopt™ (Christensen et al., 2005) includes a graphical user interface (GUI) that allows the user to select from a range of predefined and discrete building options (heating, ventilating, and air-conditioning system type, envelope constructions, etc.) to be used in the optimization process. This allows the user to rapidly generate and visualize the design space through a browser, but its flexibility is limited as a result of having predefined building options and its inability to identify a wide range of objective functions. DOE2.2 and TRNSYS are the simulation engines of BEopt™. BEopt™ was used

BS'13 Conference paper

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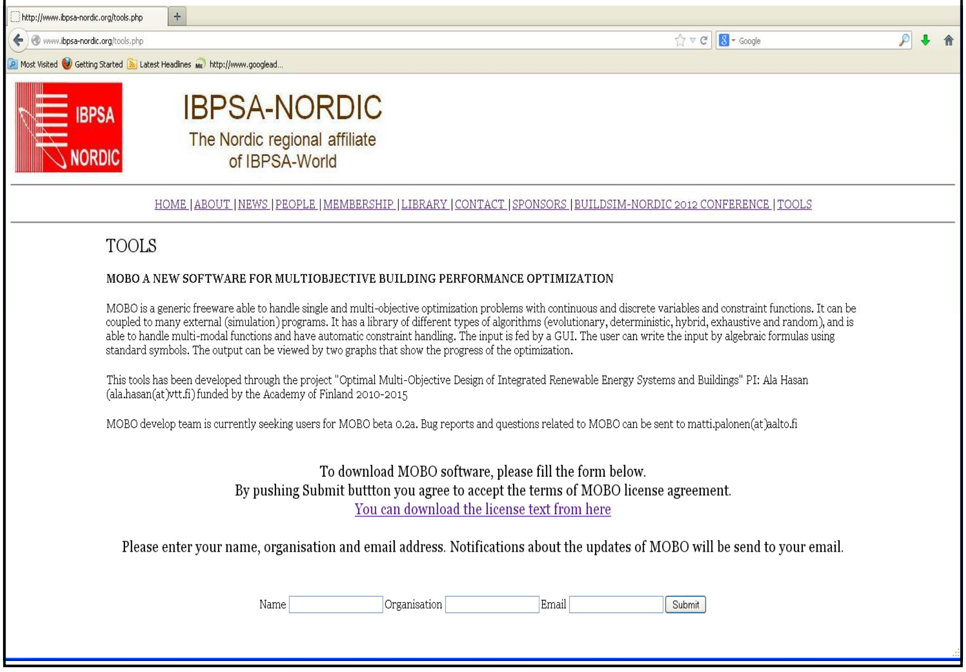

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TOOLS

MOBO A NEW SOFTWARE FOR MULTIOBJECTIVE BUILDING PERFORMANCE OPTIMIZATION

MOBO is a generic freeware able to handle single and multi-objective optimization problems with continuous and discrete variables and constraint functions. It can be coupled to many external (simulation) programs. It has a library of different types of algorithms (evolutionary, deterministic, hybrid, exhaustive and random), and is able to handle multi-modal functions and have automatic constraint handling. The input is fed by a GUI. The user can write the input by algebraic formulas using standard symbols. The output can be viewed by two graphs that show the progress of the optimization.

This tools has been developed through the project "Optimal Multi-Objective Design of Integrated Renewable Energy Systems and Buildings" PI: Ala Hasan (ala.hasan(at)vtt.fi) funded by the Academy of Finland 2010-2015

MOBO develop team is currently seeking users for MOBO beta 0.2a. Bug reports and questions related to MOBO can be sent to matti.palonen(at)aalto.fi

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