BUILDING PERFORMANCE SIMULATION MODELING TECHNIQUES

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Abstract: This research aims at demonstrating techniques in complex dynamic building energy simulation methods that greatly reduce the otherwise very time-consuming - in particular cases even week-long - computation time of simulation models, however marginal difference arises in the energy results of the simulations. Different test simulations were created to examine how to simplify the models without altering the energy and comfort results, which lead to reduce also the working hours spent on building the model. The building physics behavior of the zones, heating and cooling equipment in the complex model were studied and tested to understand how those can be used, merged or simplified in order to speed up both computation time and model building phase. The IDA ICE complex dynamic building energy simulation program offers two methods - periodic and dynamic - for calculation, which were compared in this program. Test simulations provide information about possible differences between the results of these calculation methods, in order to define the appropriate use of these methods.

Keywords: Dynamic building energy simulation, Building physics modeling techniques, Energy-efficiency, Energy optimization, Energy management, Building services systems

1. Investigation goals, test simulation set up

Today's most accurate and developed building design supporting tools are dynamic building physics simulations with significantly better and complex modeling of real physical systems than steady state calculations [1]. There are already ongoing research studies in Hungary about the energy performance and energy optimization potential of buildings, which use this different dynamic thermal building simulation methods, coupled with building monitoring measurements [2], [3], [4], [5]. Beside general

overviews of building thermal energy simulation techniques [6], [7] also building energy performance validation supporting simulation experiences possess first evidence for advanced sustainable building simulations [8], [9]. However, there are few publications about applied experiences about dynamic and periodic calculation time demand. Therefor the subject of the research is to find answers to the question on how can calculation and model building time be reduced, whilst keeping the difference of the energy results of the simulation as low as possible. Test results proved that a well-adjusted model is able to eventuate less than 0.02% difference in the calculation outcome, while its computation time can be reduced even up to 1/100.

Table I shows the simplified steps of the building energy and comfort simulation. Even though the preparation of the energy model (step 2) is just one single step along this roadmap (*Table I*), the process will determine not only the computation time - that can be even week-long - but also the outcome of the whole simulation. During the construction of the model each and every parameter must be set up very consciously, in order to avoid any unnecessary calculation iteration, time consuming over-detailing, however over-simplification of the model can cause undesirable difference in the final results. Calculation methods (periodic or dynamic) must be chosen in accordance to the purpose of the simulation, respectively investigation.

A periodic simulation means a certain period is simulated a number of times until the system has stabilized and no longer changes from simulation to simulation, a dynamic simulation means that the simulation starts at a particular time and ends at another time. A startup phase may precede the main (calculation) phase. A startup-phase is a simulation with the sole purpose of selecting a suitable starting point for the real experiment. The startup phase also preheats the thermal mass of the building structures in the simulation model.

Table I

Simplified algorithmic steps of the building energy and comfort simulation

1. Collecting and systemizing all available plans, details and data of the building to be simulated;
2. Creating the energy model in the IDA ICE software [10];
3. Setting up the parameters for building energy and climate simulation;
4. Running one-year simulations;
5. Results can be compared with the measured data;
6. Recalibrate the model;
7. Test the concepts for the improvement;
8. Model is validated to work effectively, apply to real building control.

1.1. Test building simulation defaults

To set up the parameters of the test building correctly the purpose of the simulation must be determined first. This is to find the fastest and most accurate simulation method. While searching this technique there are several questions to be answered:

1. Can similar zones merged together?
2. Can similar heating equipment merged together?
3. Are there any similarities in merging water radiators, floor-heating or fan-coils?
4. Whether dynamic or periodic simulations provide the most punctual results?
5. While using the periodic calculation method the maximum periodicity must be used or fewer repetitions could provide similarly correct outcome?
6. Are there any laws between the reps and the accuracy of the final result?
7. What is the best method to get quick and accurate result for comfort studies?

Unfortunately, no single method exists to answer all these questions at once. If this simple statement has been accepted, it leads to the recognition that several tests must be run, which means that the test building itself needs to be as simple as possible, yet all the parameters tested should be included and being able to changed easily.

The test building is a resembling of a simplified average family house: 10.0x15.0 m, 150.0 m^2 floor area, rectangular shape, 2.6 m clear height, one-story house, with the longer facades facing south and north. 4 pieces of 125x150 cm widows has been placed on the south façade, while one facing east and west to grant different solar gain during the 1-year period.

To simulate the behavior of the zone-merging two types of a floor plan have been created. The base floor plan consists one 150 m^2 zone, while the other has 4 pieces of 37.5 m^2 (total of 150 m^2) (*Fig. 1*).
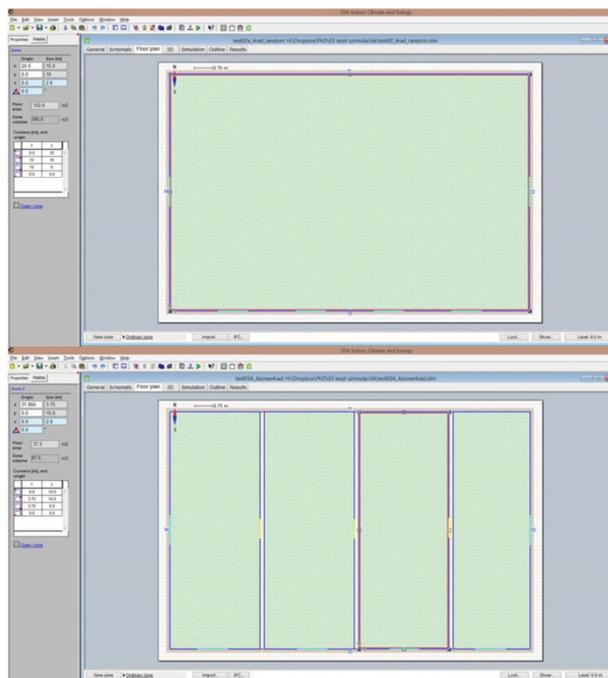
Fig. 1. Floor plans of the test building

The applied structures and measures of the outer and inner walls, windows, openings and heating equipment are the most commonly used ones. In the 4 zones layout one 50 W lighting and one 150 W equipment has been placed in each zone, while in the single zone layout a unit of 4 pieces of light (4x12.5 W) and equipment (4x37.5 W) provide the same consumption and thermal load (*Table II*).

Table II

Test building simulation defaults

1. Net floor area 10.0 m x 15.0 m, 150 m^2;
2. Net Volume: 390 m^3;
3. Outer walls: 30 cm brick + 10 cm EPS;
4. Inner walls: 10 cm gypsum, openings 100/210;
5. 6 pieces windows: 125/150, double glazing, LOW-E;
6.1. Water radiators: 1 piece 4000/900 mm 4000 W, or 4 pieces 1000/900 1000 W;
6.2. Floor heating 150 m^2, or 4 pieces of 37.5 m^2;
6.3. Fan-coil (heating) total heat transfer 12000 W, fan-coil (cooling) total/sensible heat transfer 12000 W or 4 pieces fan-coil (heating) total heat transfer each 3000 W, 4 pieces fan-coil (cooling) total/sensible heat transfer each 3000 W;
7. Default cooler: electric chiller COP 3 (theoretical 'unlimited' capacity);
8. Default heater: fuel boiler COP 0.9 (theoretical 'unlimited' capacity);
9. Default AHU: Standard AHU (theoretical 'unlimited' capacity) with heat recovery (eta = 0.6);
10. 4 light sources 50 W each, always on;
11. 4 equipment 150 W each, always on;
12. Location: Budapest;
13. Weather data: Debrecen (ASHRAE IWEC 1.1) [11].

1.2. Simulation settings - water radiator

To test the behavior of a water radiator heat system 6 test simulations were introduced. In each test only a single parameter has been changed in order to keep track of changes in the results. In test01 the whole layout consist of one zone in where 1 piece of a 4.0 m long, 0.9 m high, 4000 W heat output water radiator were placed randomly in the zone.

In test02 the 150 m^2 zone has not been modified, but 4 pieces of 1.0 m long, 0.9 m high and 1000 W heat output radiators were used. In test03 4 zones, (each 150 m^2/4=37.5 m^2) and 4 pieces of radiators (1.0 m x 0.9 m, 1000 W) in each zone were applied. In IDA ICE radiators can be placed on the exact spot on the wall, such as in real life. To examine its effect on the outcome, we introduced test01a, test02a and test03a accordingly to original tests.

1.3. Simulation settings - floor heating

For testing the floor heating system the same test building's layout have been used like in test01 to test03 (*Fig. 2*). In test04 a 150 m^2 size, 26.667 W/m^2 floor heating were placed, while in test04 and test05 4 pieces of a 37.5 m^2 26.667 W/m^2 floor heating were operated in a single zone (test05) or separately in 4 zones (test06). Total heating power of the system have been calculated (150 m^2 x 26.667 W/m^2 = 4000 W) to be equal to the water radiator heating in order to gain information on compering those systems (*Fig. 3*).

1 zone, 1 radiator, random	1 zone, 4 radiators, random	4 zones, 4 radiators, random
1 zone, 1 radiator, on the wall	1 zone, 4 radiators, on the wall	4 zones, 4 radiators, on the wall
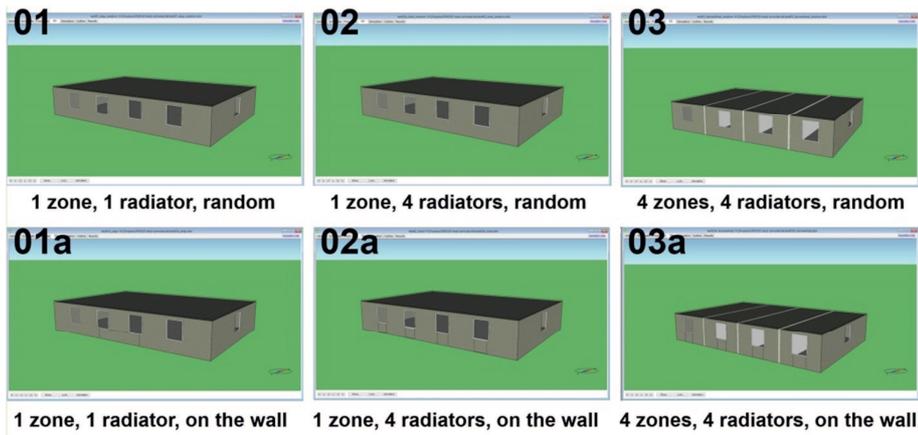
Fig. 2. Test simulation scenarios for water radiator heating

1 zone, 1 floorheating	1 zone, 4 floorheating	4 zones, 4 floorheating

Fig. 3. Test simulation scenarios for floor heating

1.4. Simulation settings - fan-coil heating and cooling

When testing the fan-coil heating and cooling system (test07-test09) (*Fig. 4*) simulations proved that using a 4000 W heating and cooling power equipment will result a very high number of dissatisfied (IV. unacceptable comfort category) when examining the EN 15251 [12] thermal comfort. In order that the results of comfort and energy consumption will be similar to the water radiator and floor heating systems 12000 W power fan-coil was used. Heating fan coil was operated form 1st of October till 31st March, while cooling fan-coil was constantly on from 1st April till 30th September.

Fig. 4. Test simulation scenarios for fan-coil heating and cooling

2. Examination of the results of simulation

Every test simulation scenarios have been run 5 times in both periodic and dynamic method and the average of the computation time and total delivered (final) energy are summarized in *Table III, IV, V*. Maximum value of the periodicity can be chosen freely when running periodic simulation. In order to be able to examine the difference between the results of different periodicity, maximum periodicity has been set to 1, 5, 10, 50 and 100. The actual maximum periodicity has been reached is recorded.

Table VI, VII, VIII demonstrate the different heating systems in the models with regard to indoor comfort qualities (comfort categories according to EN 15251) [4] in dependence of the variable heat transfer methods.

Table III

Simulation results -Final energy

			Dynamic vs periodic						
		Dynamic			Periodic				
		Time (s)	Result (kWh)		Periodicity max	Periodicity actual	Time (s)	Result (kWh)	Difference to final result
Water radiator	1zone - 1rad. Test01	26	28150	Test01	1	1	25	28320	0.11%
					5	5	128	28288	0.00%
					10	6	153	28288	
					50	-	-	-	
					100	-	-	-	
	1zone - 4rad. Test02	28	28162	Test02	1	1	28	28322	0.12%
					5	5	137	28289	0.00%
					10	5	137	28289	
					50	-	-	-	
					100	-	-	-	
	4zone - 4rad. Test03	51	28183	Test03	1	1	50	28315	0.03%
					5	5	247	28310	0.01%
					10	8	391	28307	
					50	-	-	-	
					100	-	-	-	

Table IV

Simulation results - Final energy

				Dynamic vs periodic				
		Dynamic			Periodic			
		Time (s)	Result (kWh)		Periodicity max	Periodicity actual	Time (s)	Result (kWh)	Difference to final result
Floor heating	1zone - 1floor Test04	32	29320	Test04	1	1	32	29523	0.52%
					5	5	156	29374	0.01%
					10	10	310	29372	0.01%
					50	18	679	29370	
					100	-	-	-	
	1zone - 4floor Test05	38	29421	Test05	1	1	38	29497	0.45%
					5	5	189	29361	0.01%
					10	10	375	29363	0.01%
					50	16	697	29365	
					100	-	-	-	
	4zone - 4floor Test06	64	29153	Test06	1	1	63	29322	0.38%
					5	5	310	29207	0.01%
					10	10	622	29209	0.01%
					50	21	1307	29211	
					100	-	-	-	

Table V

Simulation results - Final energy

				Dynamic vs periodic				
		Dynamic			Periodic			
		Time (s)	Result (kWh)		Periodicity max	Periodicity actual	Time (s)	Result (kWh)	Difference to final result
Fan-coil	1zone - 1FC Test07	75	27708	Test07	1	1	69	27275	0.16%
					5	5	345	27230	0.01%
					10	10	669	27231	0.00%
					50	26	1699	27232	
					100	-	-	-	
	1zone - 4FC Test08	75	27734	Test08	1	1	78	27902	0.03%
					5	5	380	27892	0.01%
					10	10	753	27895	0.01%
					50	26	1355	27895	
					100	-	-	-	
	4zone - 4FC Test09	392	27369	Test09	1	1	413	27541	0.01%
					5	5	1984	27542	0.01%
					10	10	3914	27545	0.00%
					50	22	8404	27544	
					100	-	-	-	

Table VI

Simulation results - Comfort

			Dynamic vs periodic with comfort							
			Dynamic				Periodic			
		Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)			Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)	
Water radiator	1zone - 1rad.	Test01	27	106283.6 -4939.3	1938 (I.)	Test01	167	106739.5 -4954.2	1854 (I.)
					5525 (II.)				5525 (II.)
					6304 (III.)				6299 (III.)
					2456 (IV.)				2461 (IV.)
	1zone - 4rad.	Test02	28	106279.4 -4938.6	1936 (I.)	Test02	138	106756.1 -4954.7	1874 (I.)
					5525 (II.)				5549 (II.)
					6299 (III.)				6321 (III.)
					2461 (IV.)				2439 (IV.)
	4zone - 4rad.	Test03	52	105928.9 -4934.6	3469 (I.)	Test03	399	106431.9 -4869.2	3256 (I.)
					5520 (II.)				5544 (II.)
					5929 (III.)				5953 (III.)
					2831 (IV.)				2807 (IV.)

Table VII

Simulation results - Comfort

			Dynamic vs periodic with comfort							
			Dynamic				Periodic			
		Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)			Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)	
Floor heating	1zone - 1floor	Test04	32	94337.7 -4487.8	5544 (I.)	Test04	802	94337.9 -4487.6	5544 (I.)
					5552 (II.)				5552 (II.)
					6329 (III.)				6329 (III.)
					2431 (IV.)				2431 (IV.)
	1zone - 4floor	Test05	38	94341.7 -4488.2	5544 (I.)	Test05	697	94344.6 -4488.4	5544 (I.)
					5552 (II.)				5552 (II.)
					6327 (III.)				6328 (III.)
					2433 (IV.)				2432 (IV.)
	4zone - 4floor	Test06	64	96315.9 -4431.4	5526 (I.)	Test06	1315	96318.9 -4564.1	5547 (I.)
					6366 (II.)				6369 (II.)
					8320 (III.)				8319 (III.)
					440 (IV.)				441 (IV.)

Table VIII

Simulation results - Comfort

			Dynamic vs periodic with comfort						
			Dynamic				Periodic		
			Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)		Time (s)	PPD PMV (mean*8760h)	Comfort category (EN15251)
Fan-coil	1zone - 1FC	Test07	75	122077.2 -5492.9	304 (I.) 4611 (II.) 6183 (III.) 2577 (IV.)	Test07	1699	122232.2 -5496.6	289 (I.) 4635 (II.) 6209 (III.) 2551 (IV.)
	1zone - 4FC	Test08	75	120498.5 -5442.0	383 (I.) 4626 (II.) 6206 (III.) 2554 (IV.)	Test08	1355	120626.3 -5448.1	366 (I.) 4613 (II.) 6184 (III.) 2576 (IV.)
	4zone - 4FC	Test09	392	118255.0 -5518.6	487 (I.) 5419 (II.) 8544 (III.) 216 (IV.)	Test09	8404	123177.3 -5307.0	227 (I.) 4774 (II.) 8122 (III.) 638 (IV.)

Clear regularities can be seen when the results are shown in graph. Even though in test01 to test03 (periodic calculation method) (*Fig. 5*) different layout and radiator allocation were used - although total floor area and total heating power were unchanged - difference of the results for total delivered energy was never higher than 0.41%. (28 288 kWh - 28 406 kWh). However, in terms of processing time, a more than 7.5 times difference can be seen. Notwithstanding, the simplest simulation test01 (one zone, one radiator) was expected to be calculated quickest, the simulations proved different to test02 (one zone, 4 radiators) needed the least amount of computation time.
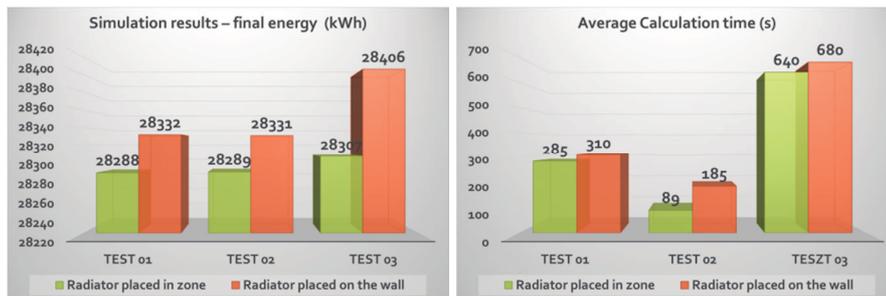
Fig. 5. Final simulation results and calculation time

As different heating system simulations (*Fig. 6, Fig. 7* and *Fig. 8*) are examined the same correlation can be found: final energy results not differ significantly, while the

same pattern can be seen at computational time as seen with the water radiator system: tests including 1 zone, 4 heat delivery equipment could be calculated faster or at least as fast as test includes 1 zone and 1 heat delivery equipment (*Table IV-V*). To calculate tests with 4 zones, 4 heat delivery equipment multiple time will be required than single zone tests.
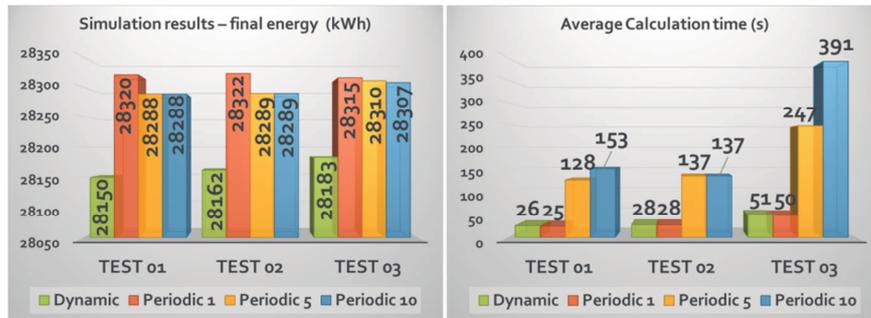
Fig. 6. Simulation results and calculation time - water radiator
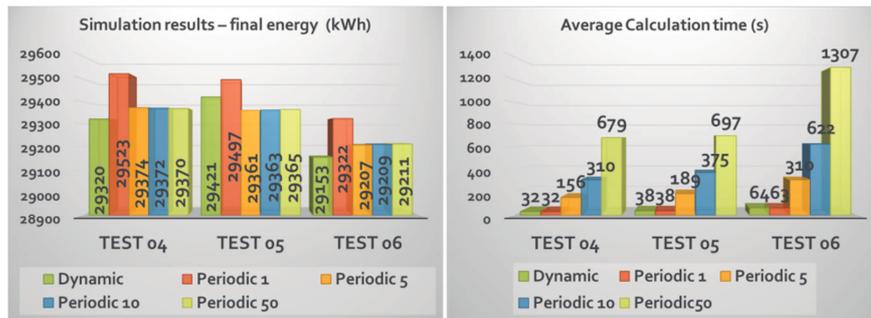
Fig. 7. Simulation results and calculation time - floor heating
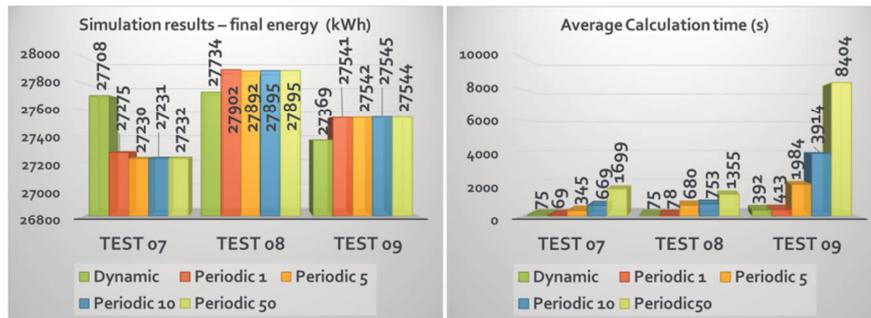
Fig. 8. Simulation results and calculation time - Fan-coil

IDA ICE complex building simulation software is capable to recalculate results automatically in periodic calculation mode till the preset tolerance level has been reached. The number of repetition can be more than 25 as seen in *Table III, IV, V*. The calculation time is directly proportional to the number of repetitions. The question arises by itself: Whether maximum periodicity must be used in every case or fewer repetition could provide similarly correct outcome? To answer that test04 and test05 were run in dynamic mode and in periodic mode 1 to 5 times and the results are shown in *Fig. 9*.
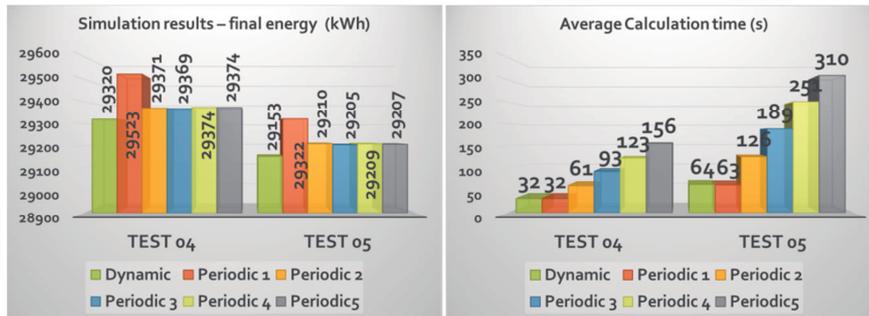
Fig. 9. Effective number of periodicity

It can be clearly stated that calculation time directly proportional to the repetition number and 1 periodic calculation time equal to the dynamic calculation time. It is also apparent that 1 periodic or dynamic calculation will not provide enough accuracy. However, after two repetitions of the calculation the result is nearly constant.

3. Conclusion

In order to speed up the model building and computation time, after the analysis of the test simulations carried out the following statements can be made:

- Similar and neighboring zones can be merged together without compromising the calculation result;
- Heat delivery equipment cannot be sum up by using one large equipment, instead of multiple ones. This technique will not decrease calculation time;
- Placing water radiators on the exact spot on the wall will make the model building and calculation longer and more difficult, but will not provide more accurate result;
- For a quick control of the model or for comfort studies dynamic or periodic method with periodicity set to 1 can be used;
- Maximum accuracy can ben reach in periodic method periodicity set to 2. More periodicity will result multiple calculation time but accuracy will not improve;
- The best compromise between quickest calculation and most accurate results delivers periodic simulation with maximum number of periods set to 2.

Acknowledgements

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