difference, but there are limitations to that approach to measuring. So in my opinion, there's not a clear answer to that question today, and it's critically needed. So it's a great question, and I would welcome and invite others to weigh in here who may have a different opinion on that.

Eva Wong: Well thanks a lot Brian, we really appreciate it, and if people have additional questions, I'm sure they can just email you. Did you include your email by the way in your presentation?

Brian Stone: I think it's on the first slide.

[Back to Slide 6: Urban and Rural Temperature Trends in Proximity to Large U.S. Cities: 1951-2000]

Slide 30: Estimating the Impacts of Climate Change and Urbanization on Building Performance

Eva Wong: Ok thanks a lot, and now we'll turn it over to Dru Crawley, who is a team leader at the Department of Energy. He's in the Commercial Building Research and Development office.

Dru Crawley: Hi, and thank you for having me today. Sorry for the garbled byline there – what I was trying to show was that although I work in the Department of Energy, this work is work that I have been doing through my PhD thesis at the University of Strathclyde in Scotland. And what I've been trying to do is look at – my topic is using single-building-scale simulation to look at how it can be used in policy. And one of things that has come up is what is the impact on buildings. If you looked at some of the IPCC reports from 2000-2001, that period, there was not a lot of information on it – there was a lot on how buildings affected that and it wasn't really any kind of reverse, how buildings operations and energy use might be compounding the problem as we go forward. So that was part of what I was looking at. So I want to go through and show you some of the things I did to look at creating some artificial – but based on all of the measurements and all of the models that I could find – some weather files that I could use in doing some simulations and then looking at the impact, so that's what this is about.

Slide 31: IPCC Climate Change Scenarios

Dru Crawley: If we go on to slide 2 – just a reminder about the climate change scenarios that are in the IPCC. There were four major storylines here to represent different demographic, social, economic, and environmental developments. Some of it was things like "business as usual," aggressive energy and environmental interventions, etc. So depending on that you get different outcomes in terms of what the predictions of the models are. From that there are four scenarios based on those storylines that really represent the range of climate impact from least to best, given the information at the time and the models. If we go on then – of course there were a number of Global Climate Models (GCMs) that were run – Hadley from the U.S., and the CSIRO from Australia, and the GCM and PCM from the U.S. and I forget where the fourth one is from – to look at that. But the results – you've got 16 combinations of scenario and climate predictions on top of what you see there.

Slide 32: Range of Annual Average Temperature Change Predicted

Dru Crawley: So when the IPCC comes together, it sort of looks like this, where we have starting today, a small change in 2001 up to changes, as Brian was mentioning, of 1.5 to 5.5 degrees C, quite wide. Of these, the Hadley – which is represented by kind of the tallest bar down to the midway HadCM3 – has kind of the best spread of things. The PCM tended to be toward the bottom, and CSIRO was kind of a different spread and didn't have as good definition.

Slide 33: Köppen Climate Regions

Dru Crawley: If we go on, I also want to then look at world climates. Vladimir Köppen – who was a biologist looking at characterizing climates for agriculture – came up with a climate schema that – based on my experience in doing simulation of climate analysis over the years – really kind of fit my gut feeling of how things were working, and I'll show you. Essentially there's this category A to H, from tropical, hot dry, mid, cold, and mid-dry up to polar and even highland climates. And then you add in hot/cold, dry/wet, other combinations of that and you get 20 subcategories.

Slide 34: Köppen Climate Regions

Dru Crawley: If we apply that to the globe – you see that you actually get differentiations based on mountains and the local climates along the coast, so we're getting some differentiation due to marine climates – it does fit what my experience was telling me with that data.

Slide 35: Representing Climate Scenarios

Dru Crawley: If we move on to slide 6 – what I wanted to do then was represent those climate scenarios using some of the existing datasets we had. The IPCC baseline period – the period that Brian was talking about as well – the best dataset that we've got in the U.S. and even internationally does cover that period, 1961-1990. And that is essentially the same as some existing typical weather files that we use in doing building energy analysis, called TMY2. So there's a good match of the datasets coming from the same piece. So based on the scenarios, these global climate models will give us changes in temperature, precipitation, cloud cover. From that I can then extrapolate, or take that information and modify my weather files. The Hadley dataset actually had the best coverage – a lot of these were 2.5 degree or even 5 degree grids around the world, which is very coarse – but Hadley, through a couple steps of reanalysis, the Hadley Center had redone that and got a 1 degree grid around the globe. And they produced average monthly temperature changes, as well as diurnal temperature changes, and cloud cover, which I could then use to modify the existing files. Now precipitation – yes it's important in the climatological part, but for the most part most of our simulation models – the building simulation models – don't take that into account today. There are a couple of exceptions, but so I did not include that in this. In addition, I wanted to capture not just this typical piece or the typical files that we've been using, but also knowing that climate data varied throughout the period of record, I wanted to look at high and low cases as well. And I also wanted to look beyond what "business as usual" or current energy standards were, to cases where energy efficiency was not in play or even part of the standard or even considered, and then the low energy case because that's one of the things we're working on. So I essentially created weather files for those scenarios to test the weather impact.

Slide 36: What do the Climate Change Scenarios look like?:

Dru Crawley: If I go on to the next slide, slide 7. So what does this make the climate change scenarios look like in an hourly dataset, how do we apply that? We usually had an average monthly temperature change associated with that – it could be a daily or diurnal temperature change, where the amount of temperature between high and low was changing. And sometimes it was positive, but more likely it was a depression or a smaller change in the diurnal temperature. I often saw a decrease in cloud cover from the data, but it was usually pretty small from what I could tell, but it did mean some change in the solar radiation, and some changes in precipitation which varied quite a lot. If I take an example – this is a chart for one day, it happens to be Los Angeles from the typical weather file for November 23rd and it had a nice pattern. If I take the yellow – that's the existing dry bulb temperature, and then the other bars represent the four ranges. Now some of those are right on top of each other so that you can't see them, because there was virtually no change between some of the scenarios. Like I think A1FI and A2 were in the same position, so you can't even see them. But here what we're seeing is that we're starting off with a base diurnal temperature, and then we've got to change the temperature for the scenario, usually a smaller one, so there's a compression of that. And it seems to be affecting – from all of the literature – it's looking at raising the nighttime temperatures significantly more, or more so than the daytime temperatures – that there seem to be some limits caused by the humidity and other things that are helping that high from going a lot higher. But we're still seeing significance there – we're going from 21 to 25 degrees C here, and that's a big change for Los Angeles in November. In addition, we're seeing the nighttime temperatures remain higher and stay higher than the daytime temperature.

Slide 37: Heat Island

Dru Crawley: If we move on, I did some work on looking at where measurements have been done for heat islands and various things – including some of the work Brian had been doing – and found Eva's website and some others to really give some background information. All of it does say heat island is a function of city population – how intense it is, how extreme the temperatures are. The ranges appear to be about 1 to 5 – I couldn't find any good numbers on that. I found one thesis from a PhD student in Houston who had done extensive measurements in a number of locations in Houston, who had gotten some pretty good temperatures and they were kind-of in the middle range – 2 to 2.5

degrees. It seems to also be a function that once you get to a certain population density – the literature says roughly 5 degrees C – you hit kind of the high end of what the heat island's doing. It also depresses the daytime temperature, so we're seeing a little bit lower hourly daytime temperature while raising the nighttime temperature. And let me show you what that pattern looks like – and this from all of the pieces I've seen, both in Europe and in the U.S. So here's an example of Dulles Airport here near Washington. The yellow line again being the existing dry bulb temperature, and then I've got two cases: a low case 1 degree change in the heat island effect, and the other being a five degree, kind of the extreme. And what we see here is a lower daytime temperatures depression – excuse me, a small amount of daytime temperature reduction. But what you see in all of the measured data is the nighttime – the temperatures remain higher, and it seems to be a case of about sunset. That the temperature just remains higher and floats lower slowly, that we're not going to – we're getting the radiation off the surfaces and out of the buildings after those hours, so the temperatures still remain higher. And those temperatures remain higher until about sunrise – again, that's an approximation, but that seems to be where that information is.

Slide 38: Test Case Building Prototype

Dru Crawley: If we move on, I wanted to then take those files that I've created, this new weather data, and test it out on a small building to see what the impacts would be. And it's a pretty typical building, about 3800 square feet, two-story, pretty typical in terms of equipment, and building fabric, and everything else. And I've simulated using our EnergyPlus simulation program.

Slide 39: Building Diagram

Dru Crawley: And this is just a diagram of it to give you a feel. It's not an untypical suburban sort of low model, and I think a small building could probably show more of the extremes than a larger building.

Slide 40: Typical vs. Actual Years

Dru Crawley: If we go on to some of the results – here's taking the building and putting it at London-Gatwick. And I had weather for several of the datasets available in the U.S., and I mentioned it was TMY2, but in other locations there's an International Weather for Energy Calculations, or IWEC, and that's the first column in my chart. The rest of this is the source data for where this typical weather file came from, so simulating using actual weather throughout the entire dataset. My thought here was that I ought to be able to pull the coolest and the warmest locations, and I would get the maximum and minimum temperature, or maximum and minimum energy, that would make sense. Unfortunately that worked only, as you can see here, in London.

Slide 41: Typical vs. Actual

Dru Crawley: If I do the same thing in Washington – if you look at where the maxes and the mins are, they're not anywhere near the warmest or coolest years. But the good thing is that it seemed that the TMY2 was approximating about the mean energy impact for the typical building.

Slide 42: Typical vs. Sorted Actual Years

Dru Crawley: But then what I wanted to do was take that and sort the years – I want to find the year that had the minimum and the maximum – use those in my further analyses. So I had a minimum case, my typical case, and maximum case, for high, low, and middle. If I move on to, and you can see at about the middle point of the years it does work.

[Back to Slide 41: Typical vs. Actual]

Dru Crawley: And in this case, if I go back – this dataset at the time was 1961 to 2004, because of some of the new hourly data that's available, so I was able to have an extended period.

Slide 43: A Snapshot of Results: Site Energy Decreases
Dru Crawley: So let's look quickly at the results. I've just a few slides, because I want to make sure Sara's got some time here. But here is an example of looking at site energy – site energy being what you would see at the utility meter. And the first three columns are dealing with the baseline case, the typical plus its high and low years from the previous slide. And then the next four set of bars are the four scenarios. And you see here in Washington, from a utility meter standpoint, we're actually seeing a decrease in energy. If you notice though, the blue is going up – that's the cooling – but the red is decreasing a lot more. But that's not all of the story.

Slide 44: But Source Energy Increases Due to Climate Changes = Increased Emissions

Dru Crawley: If we look at slide 15 – if we look at source energy – the energy it takes to provide that energy, either at the utility plant or to get the natural gas to the building – it's kind of a different story. We're seeing that the cooling in the other parts or that electricity are a much larger part of it, and the trend is almost flat here in Washington to the extreme case B2 where's it's actually a small increase.

Slide 45: And Low-Energy Buildings Can Mitigate Impacts of Climate Variation

Dru Crawley: If we look at other cases – I had a small version of the building that was a low-energy case, making it the most efficient today, and seeing what the impacts of that were. And what we found is that you see a lot less variation here on slide 16 then you would in some of the other cases. I still have a lot of data to analyze, but that kind of gives you a snapshot of how we can take the macro studies – such as the GCM or what Brian's done – and apply them at a local level of the weather files and to look at different buildings. So Eva, I'll hand it back to you.

Eva Wong: Thanks Dru. And I'm sorry about the beeping sound. Could everyone be sure to put their phones on mute by pressing *6 or using your mute button? It looks like you already have one question from A.J. at USC. But he didn't actually type in a question.

A.J. at USC: I just wanted to ask about the approach that you took in simulating the models? What parameters did you consider?

Dru Crawley: You mean for the building itself?

A.J. at USC: For the simulation.

Dru Crawley: For the simulation, I started with information from the Commercial Buildings Energy Consumption Survey, which comes out of the Energy Information Administration. And it looked at the buildings, the small offices in the lowest quartile of that, to see what the typical size and floors were. I then applied the ASHRAE Standard 90.1 which has the requirements for energy in the U.S., and used that to set the baseline for a lot of the other information. I compared it back to other studies that we've done – other real buildings – to make sure that the building was reasonable in terms of energy consumption.

A.J. at USC: Thanks.

Eva Wong: Are there other questions? Well Dru, when do you expect to finish your research? Just curious for keeping an eye out for it.

Dru Crawley: I'm expecting to finish this summer – I have all of the analysis, or I have all of the runs done at this point. And what I've done – I've got 25 locations throughout the world, large population centers with these three different cases, and now it's just a matter of getting the data – later this fall is my guess.

Eva Wong: Ok that's great. Well thanks a lot, we appreciate it. And if people later on have follow-up questions, please feel free to email Dru – I hope that's okay, Dru, for me to say that.

Dru Crawley: Sure.