Unifying paradigms for quantum refrigeration: A universal and attainable bound on cooling

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Cooling quantum systems is arguably one of the most important thermodynamic tasks connected to modern quantum technologies and an interesting question from a foundational perspective. It is thus of no surprise that many different theoretical cooling schemes have been proposed, differing in the assumed control paradigm, complexity and operating either in a single cycle or in steady state limits. Working out bounds on quantum cooling has since been a highly context dependent task with multiple answers and sometimes obscured assumptions. In this work we derive a universal bound for cooling quantum systems in the limit of infinite cycles (or steady state regimes) that is valid for any control paradigm and machine size. The bound only depends on a single parameter of the refrigerator making it easily identifiable within all control paradigms. For qubit targets we prove that this bound is achievable in a single cycle already as well as by autonomous machines.